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THE COST OF CLEAN WATER. VOLUME III. PLASTICS MATERIALS AND RESINS

IIT Research Institute
Chicago, Illinois

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The Cost of Clean Water

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

VOLUME III

INDUSTRIAL WASTE PROFILE NO. 10
PLASTICS MATERIALS AND RESINS

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THE COST OF

CLEAN WATER

Volume III

Industrial Waste Profiles
No. 10 - Plastics Materials and Resins

U. S. Department of the Interior
Federal Water Pollution Control Administration

PREFACE

The Industrial Waste Profiles are part of the National Requirements and Cost Estimate Study required by the Federal Water Pollution Control Act as amended. The Act requires a comprehensive analysis of the requirement and costs of treating municipal and industrial wastes and other effluents to attain prescribed water quality standards.

The Industrial Waste Profiles were established to describe the source and quantity of pollutants produced by each of the ten industries studied. The profiles were designed to provide industry and government with information on the costs and alternatives involved in dealing effectively with the industrial water pollution problem. They include descriptions of the costs and effectiveness of alternative methods of reducing liquid wastes by changing processing methods, by intensifying use of various treatment methods, and by increasing utilization of wastes in by-products or water reuse in processing. They also describe past and projected changes in processing and treatment methods.

The information provided by the profiles cannot possibly reflect the cost or wasteload situation for a given plant. However, it is hoped that the profiles, by providing a generalized framework for analyzing individual plant situations, will stimulate industry's efforts to find more efficient ways to reduce wastes than are generally practiced today.

James M. Quigley

Commissioner
Federal Water Pollution Control Administration

Industrial Waste Profile No. 10
Plastics Materials and Resins-SIC2821

Prepared for F.W.P.C.A.

IIT Research Institute
Technology Center
Chicago, Illinois 60616

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Federal Water Pollution Control Administration
October 1967

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SCOPE OF MATERIAL COVERED

This technical study and financial analysis considered the single-unit process, polymerization, Standard Industrial Classification (SIC) 28210. The several process steps involved, from the synthesis of the monomer to the fabrication of the completed plastic material, are under other allied SIC codes. The waterborne wastes generated by and the renovation costs incurred during polymerization are relatively low, compared with those of the other closely allied process steps.

Total production under SIC 28210 in 1967 will be 14×10^9 lb; at 6% compounded, this total is predicted* to grow to 26×10^9 lb in 1977. Current production generates a total of 113×10^6 lb of waste, expressed as 5-day biochemical oxygen demand (BOD). A total of 33×10^6 lb of BOD is untreated and goes directly to watercourses. The remaining 80×10^6 lb of BOD goes through water renovation systems, which remove 62×10^6 lb BOD; 18×10^6 of BOD passes through to the watercourse because of the inefficiency of the water renovation systems.

Thus the grand total BOD level to watercourses in 1967 will be 51×10^6 lb, or 45% of the 113×10^6 lb of BOD generated. The anticipated BOD generation for 1977 is 202×10^6 lb. On the basis of current removal (55%) by renovation equipment, the anticipated BOD level to watercourses in 1977 is 90×10^6 lb.

The total cost for water renovation under SIC 28210 is $\$2.2 \times 10^6$. This figure includes waste treatment capital goods depreciation, $\$0.3 \times 10^6$, municipal charges for treating industrial wastes, $\$0.6 \times 10^6$, and industrial operating and maintenance expenses, $\$1.3 \times 10^6$. The in-place purchase cost of capital goods in use for water renovation in 1967 is $\$7.4 \times 10^6$ (replacement value $\$7.9 \times 10^6$). The weighted economic life of water renovation equipment is 24 years.

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*IIT Research Institute study, 1967.

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SUMMARY

INTRODUCTION

This profile study of Standard Industrial Code (SIC) 28210 represents one segment of the total analysis of major contributors of water-borne pollution. Since prior investigations of this industrial classification and related fields have developed only broad generalizations, our objective was to develop more precise data. Thus the purposes of this profile study were (1) to identify, quantify and qualify processes and wastes, gross waste quantities, waste reduction practices, and waste reduction cost information, (2) to summarize these various facets of the waste picture, and (3) to make projections on future product growth. This study, as well as the previous investigations, depended upon the pollution contributor for the pertinent raw data. It is hoped that future studies, such as complete water balances for individual water basins, will find the results of our endeavor valuable.

Plastics and resins are chain-like structures known chemically as polymers. All polymers are synthesized by one or more of the following processes: bulk, solution, emulsion, and suspension. A typical production reaction requires the addition of a free radical initiator and modifiers to the monomer, the building block of the polymer. This polymerization process creates relatively little water-borne waste, compared with that of other chemical manufacturing processes. In most cases, the preliminary step in polymerization, the synthesis of the monomer,* creates considerably more waste than the production of the polymer from the monomer.**

Because it is technically and economically advantageous, most firms manufacture several different related chemical products*** at one location and use a common waste disposal unit. It is not economically advantageous to identify and qualify the waste from each manufacturing process, so waste treatment is usually handled as a common cost center. These costs are then entered into an

---

* The synthesis of the monomer is outside the scope of SIC 28210.

** For example, the cost of waste treatment for cracking ethane to make ethylene (the monomer building block of polyethylene) amounts to 0.60% of the value of the final product, polyethylene. At 11¢/lb for polyethylene, this waste treatment cost amounts to $\$2.5 \times 10^6$ for a production of 3.8×10^9 lb of polyethylene manufactured per year. There are no water-borne wastes generated from the polymerization of polyethylene.

***For example, a typical chemical complex manufactures ethylene, polyethylene, sulfuric acid, ethyl chloride, ammonia, nitric acid, and phosphoric acid.

overall burden rate. However, some firms do utilize a direct cost, based upon loading, that is charged to each producing profit center. In either case, it is often difficult for a plant sanitary engineer to accurately determine the cost of water renovation for any given manufacturing process. These manufacturing processes fall under various Standard Industrial Codes.

THE STUDY

This techno-economic study was conducted by using the following stratagem. For individual study by team specialists, SIC 28210 was separated into nine, five-digit subdivisions, representing over 85% of all plastic production.

SIC 28210	Plastics Materials and Resins
SIC 28211	Cellulosics
SIC 28212	Vinyls
SIC 28213	Styrenes
SIC 28214	Polyolefins
SIC 28215	Acrylics
SIC 28216	Polyesters and alkyds
SIC 28217	Urea and melamines
SIC 28218	Phenolics
SIC 28219	Miscellaneous resins (urethanes, epoxies, coumarone - indenes, silicones, polycarbonates, acetals, and nylon 6)

The major effort of this study involved the acquisition of first-hand organized information from the producers of plastics. Thus key production plants were visited, and the actual production facilities, in addition to the water renovation facilities, were physically surveyed. When possible, process flowsheets were obtained directly from technical personnel at the plant site. In-depth telephone interviews were conducted with resin manufacturers, major pollution-control equipment manufacturers, water pollution control chemical and service companies, government agencies, research institutes. universities, and trade and professional associations. Related technical and economic research, pollution control field work, and production experience resident at IIT Research Institute were utilized.

In order to establish past production data and to forecast future production levels, a comprehensive examination and analysis of each of the nine, five-digit plastic subdivisions was conducted. The individual and accumulated growths were plotted on three-cycle semilogarithmic paper (Figure 1).

RESULTS

Comprehensive analysis of the individual, five-digit plastic subdivisions showed that the projected compounded growth rate for SIC 28210 through 1977* is 6%. United States production of SIC 28210 and its predicted growth from 1962 are enumerated and illustrated in Figure 1 and Table 1.

The current total production of 14.25×10^9 lb/yr generates 113×10^6 lb of water-borne waste** expressed as five-day biochemical oxygen demand (BOD). Of the BOD generated, 55% (62×10^6 lb) is removed by water renovation systems; the remaining 45% (51×10^6 lb) goes to watercourses. Of the 51×10^6 lb of waste that goes to watercourses, no effort is made to treat 33×10^6 lb; the remaining 18×10^6 lb passes through treatment plants unremoved.

The predicted plastic production of 26×10^9 lb for 1977 will generate 202×10^6 lb of BOD. By assuming a constant 55% removal, the waste load to watercourses will increase from 51×10^6 in 1967 to 90×10^6 lb in 1977.

A detailed breakdown of wastes generated and costs incurred is given in Table 2. The total current waste treatment cost of removing 62×10^6 lb of BOD is $\$2.2 \times 10^6$/yr. This figure includes $\$0.6 \times 10^6$ sewer charges to manufacturers utilizing municipal facilities for water renovation, $\$0.3 \times 10^6$ for industrial water treatment capital goods depreciation, and $\$1.3 \times 10^6$ for industrial operating and maintenance of water-treating equipment. The in-place purchase cost of capital goods in use for water renovation in 1967 is $\$7.4 \times 10^6$; the replacement value is $\$7.9 \times 10^6$.***

The weighted average economic life of water renovation equipment is 24 years.

DISCUSSION

The highly subjective projections on unit growth rates and the prognostications on treatment levels and related costs given above demand some elucidation.

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* Modern Plastics (1965) predicts a growth to 22×10^9 lb in 1975. Plastic World (1966) predicts a growth to 25×10^9 lb in 1975. An IITRI study (1967) predicts a growth to 25×10^9 in 1975. U.S. Dept. of Commerce, BDSA (1967), predicts a growth to 20×10^9 lb in 1975.

** It is assumed that 1 lb dry weight of industrial waste generates 0.75 lb of BOD.

***Chemical Engineering Plant Cost Index (fabricated equipment) Sept. 1967.

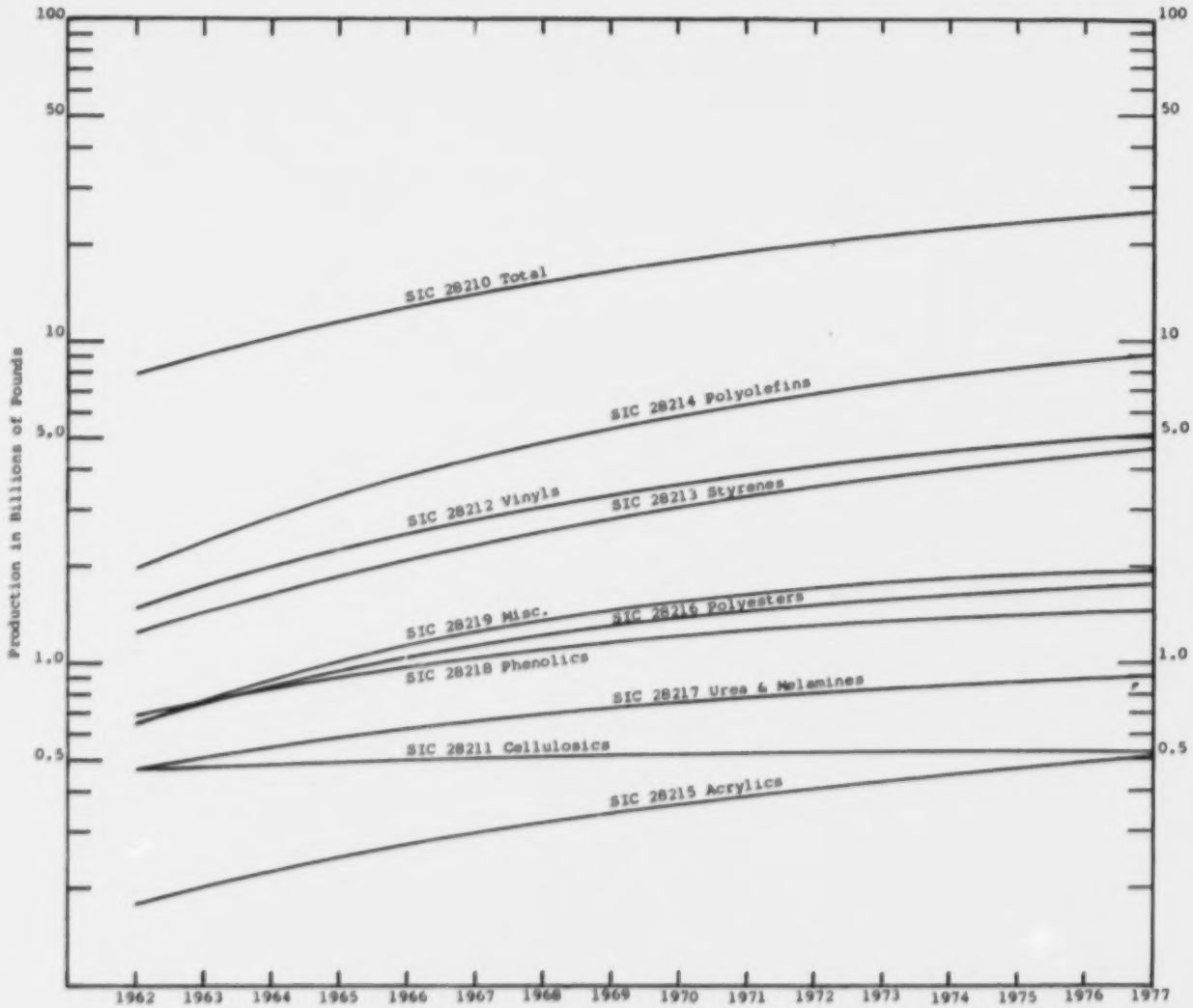

Figure 1

U.S. Production SIC 28210 in Billions of lbs/yr

Table 1

PLASTICS AND RESIN (SIC 28210) PRODUCTION IN BILLIONS OF POUNDS

Year	Total Production, 10^9 lb/year — Type of Resin									
	Cellulosics[a] (SIC 28211)	Vinyls (SIC 28212)	Styrenes (SIC 28213)	Polyolefins (SIC 28214)	Acrylics (SIC 28215)	Polyesters and Alkyds (SIC 28216)	Urea and Melamines (SIC 28217)	Phenolics (SIC 28218)	Miscellaneous (SIC 28219)	Total (SIC 28210)
1962	0.48	1.55	1.25	2.00	0.18	0.68	0.49	0.69	0.65	7.97
1963	0.48	1.75	1.50	2.28	0.20	0.76	0.51	0.76	0.76	9.00
1964	0.49	2.00	1.72	2.65	0.22	0.84	0.55	0.84	0.90	10.21
1965	0.49	2.25	1.90	3.40	0.24	0.92	0.59	0.90	1.03	11.72
1966	0.49	2.50	2.00	3.85	0.28	1.05	0.62	0.99	1.06	12.84
1967	0.50	2.80	2.25	4.35	0.29	1.10	0.66	1.05	1.25	14.25
1968	1.50	3.10	2.50	4.80	0.32	1.25	0.68	1.12	1.32	15.59
1969	0.51	3.45	2.80	5.20	0.34	1.30	0.72	1.18	1.45	16.95
1970	0.51	3.65	3.15	5.85	0.37	1.40	0.74	1.22	1.65	18.54
1971	0.52	3.84	3.30	6.20	0.39	1.45	0.77	1.28	1.68	19.44
1972	0.52	4.10	3.50	6.70	0.42	1.50	0.80	1.30	1.70	20.54
1973	0.53	4.40	3.65	7.30	0.44	1.55	0.83	1.32	1.76	21.78
1974	0.53	4.80	3.85	7.80	0.46	1.60	0.86	1.35	1.80	23.05
1975	0.54	5.00	4.20	8.60	0.49	1.68	0.89	1.38	1.85	24.63
1976	0.54	5.10	4.30	8.90	0.50	1.75	0.92	1.42	1.90	25.33
1977	0.55	5.20	4.40	9.10	0.52	1.80	0.95	1.50	2.00	26.02

[a]Includes regenerated material, e.g., cellophane.

Table 2

COST OF WASTE TREATMENT IN 1967

	SIC 28[illegible][a]	SIC 28211[b]	SIC 28212[c]	SIC 28213[d]	SIC 28214[e]	SIC 28215[f]	SIC 28216[g]	SIC 28217[h]	SIC 28218[i]	SIC 28219[j]
Production, 10^9 lb/yr	14.25	0.50	2.80	2.25	4.35	0.29	1.10	0.66	1.05	1.25
Waste water, 10^9 gal/yr	24	15	2.80	3.38	0.004	0.015	2.30	0.062	0.077	0.603
Waste produced, 10^6 lb/yr	-	10	28	2.25	-	0.174	6.6	36	52.5	0.31
% Treated	-	40	31	95	-	95	63	90	90	90
Waste treated, 10^6 lb/yr	-	2.5	8.68	2.25	No waste	0.17	4.2	32	47	0.28
Treatment cost, ¢/lb BOD	-	4	9	-	-	22	-	-	-	12
Capital depreciation, ¢/lb BOD	-	1.8	1	-	-	19	-	-	-	5
Operation and maintenance, ¢/lb BOD	-	2.2	8	-	-	3	-	-	-	7
Treatment cost, $/$10^6$ gal	-	30	-	119	-	2570	-	197	6600	483
Capital depreciation, $/$10^6$ gal	-	13	-	-	-	2320	-	105	650	184
Operation and maintenance, $/$10^6$ gal	-	17	-	-	-	350	-	92	5900	299
Treatment cost, 10^3 $/yr	2177	180	889	382	0	38	181	11	462	34
Capital depreciation, 10^3 $/yr	312	80	124	-	0	33	8	3.3	51	13
Operation and maintenance, 10^3 $/yr	1320	100	765	-	0	5	18	2.9	408	21

[a]Waste water, expressed in gal/yr, does not include cooling water. Concentrations of waste are extremely variable; a "percent treated" calculation would be misleading.

Waste produced, in lb/yr, is composed of lb BOD and lb dry wt. of a specific waste, etc., and is not an accumulative figure, nor can one form of waste be directly related to another form of waste.

Percent treated is calculated from and relates directly to waste generated; the increments are not accumulative.

Treatment cost, in ¢/lb of BOD treated, is calculated when waste is expressed in LOD and accurate relevant data are available. A weighted average is not meaningful.

Treatment cost, total treatment in $/yr, includes municipal sewer charges in the total treatment cost. No costs are entered for depreciation or operations and maintenance for municipal sewer charges. These costs are accumulative.

[b]Waste is in BOD. Production is 2/3 regenerated cellulose (60% of waste treated) and 1/3 cellulose (35% of waste treated).

[c]Waste composed of 28×10^6 lb BOD and 4.3×10^6 lb suspended solids. Treatment 54% primary treatment ($114,000/yr), 31% secondary ($775,000/yr), and 15% untreated.

[d]Waste is expressed in lb dry material. All waste is treated in municipal plants; costs are based on sewer charges.

[e]No water waste produced.

[f]Waste in BOD; difficult to treat acrylic emulsion.

[g]Waste in BOD. Treatment cost based upon sewer charges for 1.1×10^9 gal/yr at $113/$10^6$ gal; primary treatment for 132×10^6 lb produced at 2×10^4 $/lb produced; and 7.7×10^6 lb produced at 4×10^3 $/lb produced for land disposal.

[h]Waste in lb of urea, melamine, and formaldehyde. Treatment costs based upon municipal primary, 63% and lagoons 27%.

[i]Waste in lb of phenol. Treatment costs based on solvent extraction treating, 70%; lagoons, 10%; thermal incineration, 10%; and municipal, primary, 10%.

[j]Waste in lb of BOD; waste water from epoxy, 425×10^6 gal/yr; polycarbonates, 40×10^6 gal/yr; silicons, 60×10^6 gal/yr; and coumarone-indene, 78×10^6 gal/yr. Treatment costs and waste produced data only available on coumarone-indene.

For this study, 35 significant parameters were utilized to evaluate waste loading. Of these, BOD was the most representative of the waste load, as well as the one criterion most universally utilized for measurement. Because the major pollutional effect of organic wastes in a stream is their consumption of dissolved oxygen under the influence of microorganisms living in the stream environment, the rate and extent of oxygen depletion is customarily evaluated by the BOD test. Although BOD is currently the best test available, it is not an adequate parameter of organic loading, and, as a production monitor, it is "five days late."

The BOD test involves, first, a measurement of the dissolved oxygen initially present in the sample of water containing the waste under study. This sample may be from the polluted stream, or it may be a batch of special water to which a known amount of waste has been added. Other samples of mixed water and waste are then incubated in the presence of suitable microorganisms and nutrients in an appropriate environment, usually for 5 days at 20°C. The remaining dissolved oxygen is then measured, and the amount of dissolved oxygen consumed during the test is reported as milligrams of oxygen per liter of water. There are many possible interferences in the BOD test; e.g., toxic materials invalidate it completely unless they can be detoxified or diluted to the point of negligible effect.

It is customarily accepted that the five-day BOD test represents 70% of the organic load* in water from aqueous systems containing sanitary waste. For industrial wastes, however, BOD test data must represent something less than 70% because the diverse constituents of industrial waste complex the biodegradation process and too often invalidate the test. The exact percentage varies sharply, depending upon the biodegradability of the waste and whether the ideal bacteria have been utilized in seeding the test. The waste-loading data accumulated in this study are as accurate as possible, but it must be remembered that these data are based upon a test that was developed for sanitary waste and that it is inadequate for chemical industrial waste.

Many renovation systems in current use were designed and developed to produce a water whose quality will not meet the standards of the next decade. Most fluidized culture systems for housing the biological oxidation process (conventional activated sludge, tapered aeration, contact stabilization, extended aeration, aeration ditch, completely mixed systems, oxidation ponds, aerated ponds, trickling filter) were developed to treat municipal wastes. This type of waste contains a relatively low fraction of readily biodegradable soluble organics with balanced nutrients. But industrial wastes are high in slowly biodegradable soluble organics without balanced nutrients. Therefore upgrading the effluent quality from

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*Standard methods list five-day BOD for 300 mg/liter of glucose as 224 ± 11 mg/liter, or 70% of the theoretical oxygen demand of 321 mg/liter.

these marginally designed systems will reveal engineering inadequacies and subsequently develop waste treatment quality and cost problems.

Increasing the percent waste removal will involve a disproportionate increase in the cost per unit of waste removed in improperly or inadequately designed equipment. The current cost of efficient primary plus secondary treatment for a given industrial waste is in some cases five times as great, per unit volume of comparable waste water treated, as for token primary treatment systems built 10 years ago. The data available on comparable raw wastes and similar removal efficiencies were not sufficient to accurately calculate comparable costs per unit of waste removed, but, in general, those plants recently designed and built reflect total treatment costs considerably higher for a comparable volume of water treated. The data available indicate that the initial cost of recently built equipment, which is designed to reduce effluent waste loads within anticipated legal limits, was considerably higher than that of older units built for less rigorous standards.

The data accumulated in this study, i.e., waste loads generated, percentage removed, and costs incurred, were supplied by the same industrial organizations that are generating these wastes. It is possible that some of the data received favorable interpretation before release. For example, the amount of waste attributed to intermittent spills and machine and floor washdown for specific processes was difficult to isolate and evaluate.*

Ultimate disposal of solid wastes generated by biodegradation is customarily handled by using the waste for land fill. With the increasing value of land, it can thus be assumed that the cost of ultimate disposal will increase. For each pound of BOD, approximately one-half pound of solid waste is generated. It is known that four industrial plants are disposing of their solid waste by incineration. The cost of disposal by incineration is 6¢/lb of dry waste, or 3¢/lb of BOD removed.

The data available on some plastics were not sufficient to develop a total figure for percent of industrial waste water treated in municipal systems.

The anticipated growth of SIC 28210 is calculated at 6% compounded per year, although the growth rate over the past 20 years has ranged between 12 and 16% compounded per year. Thus any waste treatment program developed for the coming decade could prudently contain a contingency for accommodating a growth rate as high as 15% compounded per year.

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*One plant studied created its entire waste load from spills and washdown. The waste treatment costs amounted to 0.25% of the product value; at a product value of $\$8 \times 10^6$, this particular source of waste cost $\$20 \times 10^3$/yr for removal.

SECTION I

SIC 28211 CELLULOSICS

Cellulosics, which are plastic materials produced from cellulose, range from regenerated cellulose, or cellophane, to the nitrocellulose in gun cotton. The total demand for cellulose in this country in 1963 was about 480 million pounds. Of this, almost three-quarters was used for the production of cellophane film. The remainder was used for other cellulosics, mainly acetates.

Cellulosic plants are located in fairly remote parts of the country along large streams. These plants make little of anything else, and the effluent outputs can easily be identified. The BOD in the waste can be attributed to cellulose. Precise data are lacking, but the levels are high.

Neutralization has been practiced for years; secondary treatment is a recent innovation.

The product growth curve is on, and will remain on, a plateau over the below indicated period:

Year	Production 10^9 lb/yr
1962	0.48
1963	0.48
1965	0.49
1967	0.50
1970	0.51
1977	0.55

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

Cellulosics are manufactured from cellulose. Either cotton linters or purified wood pulp is used as the raw material, although today very little cotton linters is used. In either case, the process is the same.

1. Regenerated Cellulose

The largest portion of cellulose is used for the production of cellophane, or regenerated cellulose. In the United States, cellophane is made almost exclusively by the xanthate process, whereas in Europe, the cuprammonium process is widely used. The xanthate process is a solution process in which cellulose is treated with caustic soda and carbon disulfide in water. The resultant solution of cellulose xanthate is coagulated, and cellulose is regenerated in the form of a continuous film, or filament, by acidification. Much of the operation is proprietary, although the overall process is well known. The level of waste

has been reported to range from 0.015 to 0.01 BOD/lb of product produced. No major changes in manufacturing operations have been made in the last twenty years.

2. Cellulose Esters

The remainder of cellulosic production is largely made up of the esters: cellulose acetate, cellulose propionate, cellulose butyrate, and their copolymers. Little cellulose nitrate is made. The market for this type of cellulose thus seems to be less than 2% of the total, and there is no apparent trend to increase.

Cellulose acetate is made in a suspension process from cellulose and acetic anhydride in a sulfuric acid solution. The reaction is carried out to the triacetate stage ; the product is then de-esterified to a suitable level, precipitated, washed, bleached, and dried. A diluent of acetic acid or methylene dichloride is used. The process for making cellulose acetate is basically the same as it has been for the last 20 years.

The proprionate and the butyrate are made by essentially the same process. All three can be made in the same plant. Later they are made together as copolymers.

Figures 2 and 3 are flow diagrams of these processes.

B. Significant Water Wastes

This industry is responsible for a relatively high production of biodegradable cellulosic waste materials, sulfates, and heavy metals.

1. Regenerated Cellulose

The level of generated waste has been reported over a range of 0.015 to 0.10 lbs/lb product manufactured. The percent of product going to waste has gradually been decreasing because of the increasing efficiency in plant operations.

The bulk of the remainder of the waste is reported to be H_2SO_4, Na_2SO_4, and heavy metals. Neutralization of acids with caustic is a common practice. In some operations CS_2 is considered to be a problem; CS_2 is a poison which, if present, would interfere with the biodegradation of the waste. Scrap cellophane is also a waste that requires disposal; it is buried or incinerated.

2. Cellulose Esters

The waste from acetate production is similar to that from cellophane production. In addition, acetic acid (and methylene dichloride) are present as organic wastes, but there is no CS_2, Na_2SO_4, or NaOH. The recovery in the acetic cycle is better than 90%. The cellulose loss is approximately 1 to 8%, depending on the quality of pulp. Methylene dichloride losses are less than 2% in the processes that use it. The process for making cellulose acetate is basically the same as it has been for the last 20 years. The wastes from the propionate are basically the same as those from the acetate but are slightly greater for the

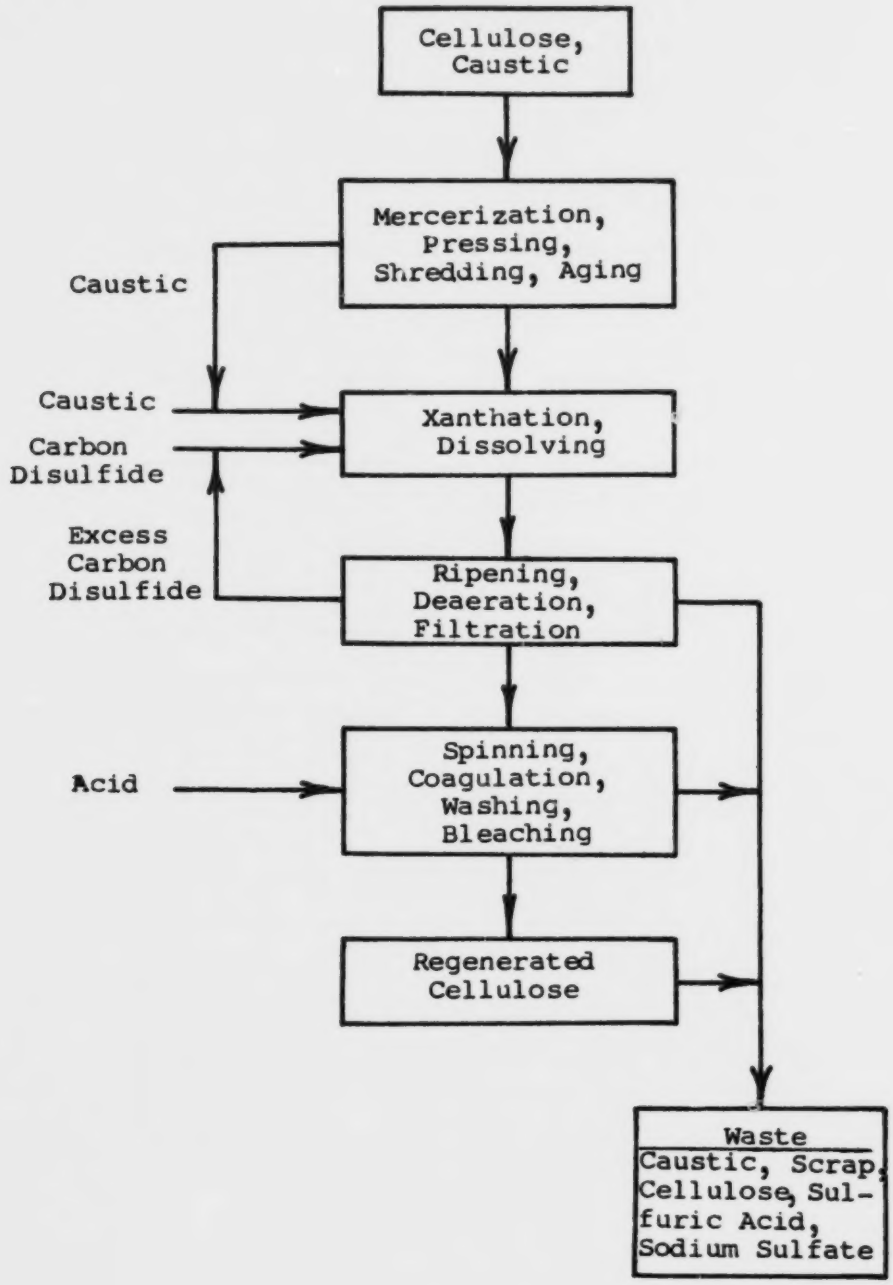

Figure 2

FLOW DIAGRAM OF THE PRODUCTION OF REGENERATED CELLULOSE

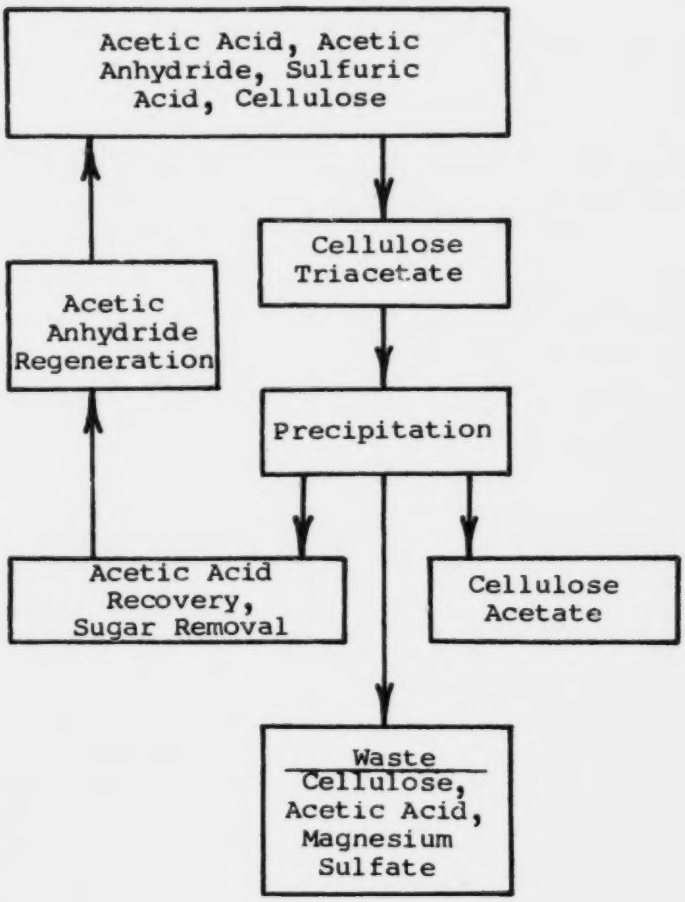

Figure 3

FLOW DIAGRAM OF THE PRODUCTION OF CELLULOSE ACETATE

same amount of product. A similar situation probably exists for the butyrate.

C. Reuse of Process Water in 1964

There is no reuse of process water.

D. Industry Subprocess Mix

There is no subprocess mix for the production of either cellophane or cellulose esters.

E. Difficult Waste Control Problems of Subprocesses

There are no subprocesses.

F. Levels of Technology

1. Typical

Typical technology for cellophane production is the xanthate process, a solution technique. Typical technology for the production of other cellulosics is esterification by suspension techniques.

2. Older

The older technology for both types of cellulosics is the same as the typical technology.

3. Advanced

There are no indications of any advanced technology.

Technology Level	Range of Plant Size, 10^6 lb/yr
Typical and older for regenerated cellulose and cellulose esters	10-100

No reliable data are available for percentages of small, medium, and large plats.

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volumes for One Plant

	Typical Technology Wasteload, 10^6 lbs BOD/yr	Wastewater Volume, 10^9 gal/yr
Cellophane (small plant, 15×10^6 lb/yr	0.3	0.45
Cellulose Acetate (medium plant, 36×10^6 lb/yr	0.72	1.08

There is no significant variation in loadings caused by shift, daily, or seasonal changes.

There is no significant difference in unit waste production for plants of significantly different production output.

B. Total Waste Quantities and Wastewater Volumes

	Wasteload, 10^6 lb BOD.yr	Wastewater Volume 10^9 gal/yr
Regenerated cellulose	6.4	10
Cellulose esters	3.2	5

C. Total Waste and Wastewater Quantities/Unit of Physical Product

	Wasteload, lb BOD/lb product	Wastewater Volume, gal/lb product
Regenerated cellulose	0.02	30
Cellulose esters	0.02	30

D. Total Waste Quantities and Wastewater Volumes Produced in Base Year 1963

	Wasteload, 10^6 lb BOD/yr	Wastewater Volume 10^9 gal/yr
Regenerated cellulose	6.4	10
Cellulose esters	3.2	5

E. Projected Gross Wastes and Wastewater Volumes

	Year					
	1969	1969	1970	1971	1972	1977
Wasteload 10^6 lb BOD/yr	9.6	9.8	9.8	10	10	10.5
Wastewater volume 10^9 gal/yr	15	15.3	15.3	15.6	15.6	16.5

F. Seasonal Waste Production Patterns

Seasonal variation in waste production are not significant. Production is maintained 24 hr a day, 7 days a week. Future seasonal changes are not anticipated. Variations in waste production due to variable demand for cellulosics are possible.

III. WASTE REDUCTION PRACTICES

A. Processing Practices

1. Waste Reduction Efficiency (%) of a Given Subprocess Relative to Alternative Subprocesses

There are no subprocesses.

2. Sequential Requirements and Interdependencies of Processes Affecting Waste Production

The proprietary and complex nature of the processes involved prevent an intelligent, accurate answer to this question.

B. Treatment Practices

1. Normal Removal Efficiency (%) of Waste Treatment Methods in Treating Waste from a Plant of Typical Technology

The efficiency of a waste treatment plant practicing secondary treatment is 70%.

One common practice in this industry is to locate near a river, use the river water on a once-through basis, and discharge the wastes directly to the river. Waste treatment seems to be a very recent development. Many of the producing plants are located in remote areas where the streams can accept and handle a high waste load. For these and other reasons, we estimate that slightly less than 40% of production practices waste treatment; most of these installations are of recent vintage. Newer treatment methods vary. In one plant, CS_2 is not considered a problem; in another, CS_2 is rendered innocuous before discharge. This plant's spent acid is neutralized by combination with a basic effluent from another process. Limestone neutralization of the cellophane spent acid is used when necessary.

2. Rate of Adoption of Waste Treatment Practices

Treatment	Estimated % of Plants Employing Treatment Method				
	1950	1963	1967	1972	1977
Neutralization	10	50	80	100	100
Contact stabilization	5	20	40	80	90

Most treatment plants that do not now have treatment facilities reportedly have plans for total waste treatment methods to be completed within a few years.

3. Combined Wastes

a. Percentage of Waste Discharged to Municipal Sewers

Little or no waste is discharged to municipal sewers.

b. Waste Removal Problems Caused by Combining Industrial with Municipal Wastes

Combination of cellulosic wastes with municipal wastes is technically feasible if the plant is located near a large municipality. Neutralization, coagulation and sedimentation would be necessary before introduction into a municipal system. The natural nutrients found in municipal sewage would be a benefit to the biodegradation of the cellulosic waste. Unless the municipal system were specifically designed for a high hydraulic loading. (30 gal. waste water per pound of product) a typical municipal system could easily be over loaded with the waste from a typical cellulose producing plant.

C. By-Product Utilization

There are no by-product uses of wastes that reduce wasteloads reaching watercourses nor is there a likelihood of any being developed and marketed in the next 10 years.

D. Base Year Net Waste Quantities

No accurate data are available to permit calculation of net waste quantities reaching watercourses in 1963. It is estimated that 9.6×10^6 lb BOD were produced and that 7.5×10^6 lb reached watercourses in 1963.

E. Projected Net Waste Quantities

No accurate data are available to permit calculations of projected net waste quantities. Well-designed secondary treatment plants are approximately 70% efficient in BOD removal.

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value* and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facilities

Treatment cost	180×10^3 $/yr
Capital goods depreciation	80×10^3 $/yr
Operating and maintenance	[illegible] $/yr

B. Capital Cost and Economic Life of Processing and Waste Removal Treatment Equipment

Capital cost	1.6×10^6
Economic life	20 years

*Data on age and replacement value is not accurately known.

SECTION 2

SIC 28212 VINYL RESINS

The homopolymers and copolymers of vinyl chloride are among the oldest and the most versatile thermoplastic resins. During the past two decades, there has been a steady growth in the production and use of a wide variety of vinyl resins. During the past few years, the growth rate of this industry has been estimated at about 8 to 12%. The total production capacity was about 1.6 billion lb/year during 1963, and it is currently over 2.5 billion lb/year. There has been very little change in the manufacturing techniques and equipment employed in this industry during this growth period. The production of the resins is essentially by means of batch operations. Among the major polymerization processes available for the manufacture of vinyl resins, i.e., suspension, emulsion, solution and bulk processes, the suspension method is the most widely used. The latter accounts for over 85% of the total polyvinyl chloride manufacture.

The production capacity of the vinyl resins during the past five years and the projected figures for the next ten years are as follows:

Year	Production, 10^9 lb/yr
1962	1.55
1963	1.75
1965	2.25
1967	2.80
1970	3.65
1977	5.20

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

The fundamental method employed for the manufacture of vinyl chloride polymers and copolymers can be one of the following three: (1) suspension, (2) emulsion, or (3) bulk polymerization. Suspension polymerization is the most widely used process for manufacturing vinyl resins in terms of the variety and quantity of polymer products produced and accounts for 85 to 90% of the total vinyl resins produced. In this method, the monomer is dispersed as small droplets into a stabilized suspending medium consisting of water containing 0.01 to 0.50% by wt. (on the basis of the monomer weight) of the suspending agents such as polyvinyl alcohol, gelatin, and cellulose ethers.

The suspension is then heated in a reactor in the presence of catalysts such as the benzoyl, lauroyl, and tertiary-butyl peroxides (0.1 to 0.5% by wt. of the monomer) in order to initiate polymerization. When polymerization is complete, the polymer suspension is taken to a blow-down tank or stripper where residual unreacted monomer is recovered. The stripped polymer is then transferred to a blend tank where it is mixed with sufficient other batches to form a lot. Finally, the polymer slurry mix is pumped to centrifuge where it is washed and dewatered. The product is then dried in rotary driers. A simplified flow diagram for the suspension process for polyvinyl chloride is shown in Figure 4. It should be noted that a highly guarded factor in this process is the suspending agent.

The emulsion polymerization process accounts for about 10% of the total vinyl resins produced. This method consists of solubilization and dispersion of the monomer and dispersion of the polymer in the solvent phase. The solvent is usually water, although in some cases cyclohexane and tetrahydrofuran are used. When polymerization is complete, a milk-like latex of permanently dispersed polymer is obtained from which the polymer particles are recovered mostly by spray-drying or in some cases by coagulation and centrifugation. The emulsifiers consist of a wide variety of soaps or surfactants, and the initiators consist of persulfates, hydrogen peroxide, and several redox systems.

Bulk and solution polymerization methods are not being widely used for the manufacture of polyvinyl chloride.

B. Significant Water Wastes

Since suspension polymerization constitutes the most widely employed process for polyvinyl chloride (85%), significant wastes from this method will be considered. In the emulsion process, which uses water as the dispersion medium, the waste products are mostly discarded into the atmosphere. However, when solvents such as hexane and tetrahydrofuran are used, effluent wastes have to be considered.

The effluent stream from the centrifugation step (see Figure 4) contains the majority of the contaminants from the plants. The impurities in the effluent stream include: (1) suspending agents, (2) surface-active agents, (3) catalysts or initiators, (4) small amounts of unreacted monomer, and (5) significant amounts of very fine particles of the polymer product. Since the suspending agent and catalyst concentrations are closely guarded, proprietary information, the nature and extent of their presence in the effluent streams can only be indirectly evaluated by means of BOD and COD data obtained from the industry. In addition to these contaminants, there may be small amounts of phenol, sodium phenolate, and sodium hydroxide, which could come from the purification of the monomer. It is also possible that chlorinated organic solvents, such as carbon tetrachloride and chloroform, which are included in the starting mixture to arrest the polymerization at any desired point, might find their way into the effluent streams.

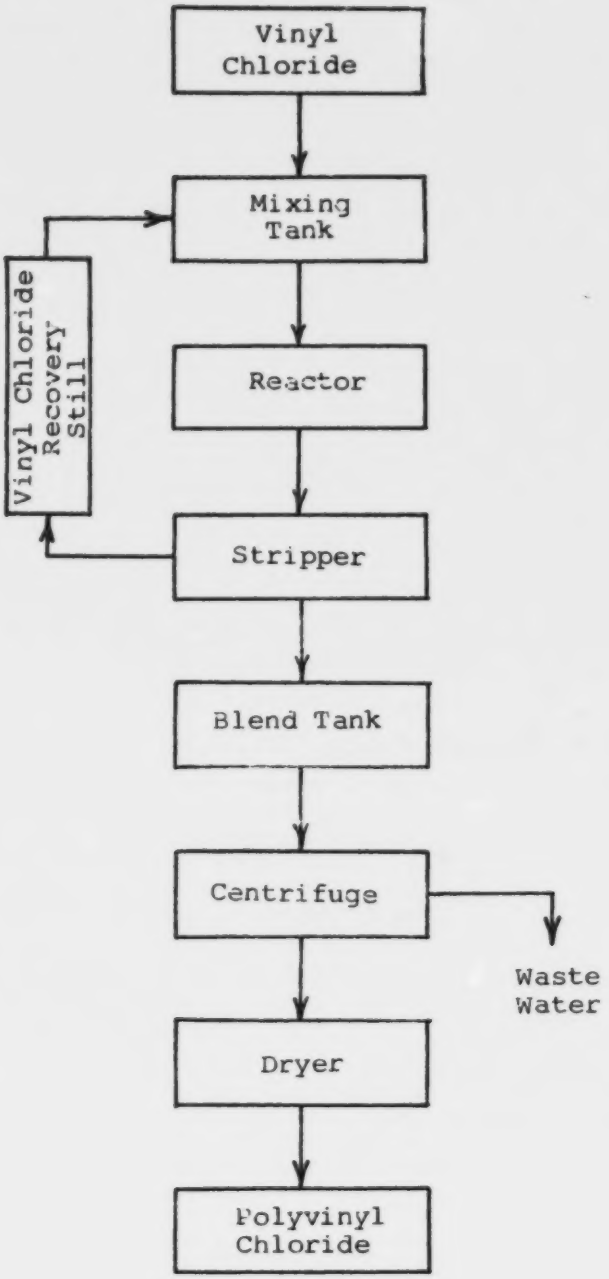

Figure 4

FLOW CHART FOR POLYVINYL CHLORIDE PRODUCTION

Data on the average composition and concentration of the water wastes from the vinyl resin industry are presented later in this section.

Air-discharged wastes may be considered negligible in the case of suspension polymerization, which is the most widely used process for the vinyl chloride homo- and co-polymers.

C. Reuse of Process Water in 1964

Waste waters from polyvinyl chloride industries are not being reused. After appropriate treatment, to decrease the contaminant present in the effluent to a low and acceptable value, the effluent waste waters are discarded into municipal sewers or river streams. In the case of solution polymerization, 90 to 95% of the solvent is being reused.

D. Industry Subprocess Mix

Suspension polymerization is the most widely used method for the manufacture of polyvinyl chloride. However, for the production of copolymers, emulsion and solution polymerization are being employed to a significant extent. There has been little change in the manufacturing methods and technology of the vinyl resins during the past 17 years, and it is believed that no drastic changes are expected in the foreseeable future. Therefore, the character of the waste effluents may not be expected to change to any significant degree in the coming 10 years. The waste water volumes might vary with the increase in total production of the resins.

E. Difficult Waste Control Problems of Subprocesses

This is not applicable.

F. Levels of Technology

1. Typical technology is described in Section IA.
2. Older technology is the emulsion process.
3. Advanced technology would be solution polymerization.

Technology Level	Range of Plant Size, 10^6 lb/yr	Plant Size, %		
		Small	Medium	Large
Typical (suspension process)	2-200	40	37	23
Older (emulsion)	2-100	90	10	
Advanced (solution and bulk)	2-100	90	10	

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volume for an Average Size Plant Producing 100 Million lb of Vinyl Resins per Year

	Waste Load, 10^6 lb/yr		Waste Water Volume, 10^6 gal/yr
	BOD	SS	
Polyvinyl chloride	1.0	0.15	100-200

In general, loadings are fairly steady. No significant changes were indicated in daily, monthly, or seasonal handling.

No significant changes in the character and pattern of the wastes and waters are expected for the next 10 years. However, the gross wastes and waste water volumes are subject to changes as a function of increased production.

B. Total Waste Quantities and Waste Water Volumes

	Waste Load, 10^6 lb/yr			Waste Water Volume, 10^9 gal/yr
	SS	BOD	COD	
Vinyl polymers	3.5	23.3	14	2.33

C. Total Waste and Waste Water Quantities per Unit of Physical Product

	Waste Load, lb/lb product			Waste Water Volume, gal/lb
	SS	BOD	COD	
Vinyl polymers	0.0015	0.01	0.006	1-2

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year 1963

	Waste Load, 10^6 lb/yr			Waste Water, 10^9 gal/yr
	SS	BOD	COD	
Vinyl polymers	2.4	16	9.6	1.6

E. Projected Gross Wastes and Waste Water Volume

Year	Waste Load, 10^6 lb/yr BOD	SS	COD	Waste Water Volume, 10^9 gal/yr
1968	23.3	3.5	14	2.33
1969				
1970				
1971				
1972	46.6	7.0	28	4.8
1977	50.0	8.0	31.0	5.2

F. Seasonal Waste Production Patterns

There are no seasonal variations in the patterns of waste production.

III. WASTE REDUCTION PRACTICE

A. Processing Practice

1. Waste Reduction Efficiency of a Given Subprocess Relative to Alternative Subprocess

There are no subprocesses involved in vinyl polymer production.

2. Sequential Requirements and Interdependencies of Processes Affecting Waste Production

This is not applicable.

B. Treatment Practices

1. Normal Removal Efficiency (%) of Waste Treatment Methods in Treating Waste From a Plant of Typical Technology

Removal Method	Normal Removal Efficiency, % BOD	COD	SS
Primary clarification method	<1	<1	98
Total treatment involving activated sludge method	88	90	98

2. Rate of Adoption of Waste Treatment Practice

Method	Estimated % of Plants Employing Treatment Method				
	1950	1963	1967	1972	1977
Primary clarification	--	--	60		
Total Treatment	--	--	40	>90	

There are no sequential applications of the processes that would affect waste reduction.

There are no substitute techniques in use.

There are no interdependencies among waste removal techniques that affect costs or relative efficiencies.

3. Combined Wastes

a. Percent Wastes Discharged to Municipal Sewers

Year	% Waste Discharged to Municipal Sewers
1950	
1963	~ 60
1967	~ 60
1972	

b. Waste Removal Problems Caused by Combining Industrial with Municipal Wastes

A number of vinyl resin manufacturers do in fact discard waste waters into municipal sewers after a primary treatment. Apparently this arrangement has been found technically feasible. There are no difficult problems created by this practice.

Primary treatment aimed at removing the fine particles of the resins is considered necessary, and this is being done by most of the resin manufacturers.

C. By-product Utilization

There are no by-product uses of wastes that reduce waste loads reaching water courses.

No new by-products are likely to be developed and marketed in 1968 to 1977.

Table 2

SUMMARY OF BASE YEAR AND PROJECTED NET WASTE LOADS

Year	Type of Waste	Gross Waste Quantity Generated, 10^6 lb/yr	% of Waste Reduced	Net Waste Quantity Discharged, 10^6 lb/yr
1963	BOD	16.0	~1	15.8
	SS	2.4	98	0.05
	COD	9.6	~1	9.5
1968	BOD	23.3	35	15.1
	SS	3.5	98	0.07
	COD	14.0	36	9.0
1972	BOD	46.0	75	11.5
	SS	7.0	99	0.07
	COD	28.0	77	6.4
1977	BOD	50.0	84	8.0
	SS	8.0	99	0.08
	COD	31.0	86	4.3

D. Base Year Net Waste Quantities

Waste	Net Waste Quantities Reaching Water Courses in Base Year 1963, 10^6 lb/yr
BOD	6.4
SS	0.1
COD	3.9

E. Projected Net Waste Quantities

These data are given in Table 3.

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facility (1966)

Treatment cost	889×10^3 \$/yr
Capital good depreciation	124×10^3 \$/yr
Operating and maintenance	765×10^3 \$/yr

B. Capital Cost and Economic Life of Processing and Waste Removal Treatment Equipment

Typical Technology	Capital Cost, \$	Annual Operating and Maintenance Expenditure, \$	Economic Life, years
Small Plant End-of-line treatment	40,000	2,000	40
Medium Plant End-of-line treatment	200,000	90,000	20
Large Plant End-of-line treatment	400,000	150,000	20
Total Capital Cost		$\$2.5 \times 10^6$	
Economic Life		20 yr	

There are no reductions in processing costs due to recovery of any possible by-product or unreacted monomer and solvent.

The question of incremental costs in applying different techniques to existing plants does not arise since the manufacturers do not anticipate any change in techniques for the projected period.

SECTION 3

SIC 28213 POLYSTYRENE RESINS AND COPOLYMERS

Polystyrene's excellent combination of physical properties and ease of processing by injection molding and extrusion make it a unique thermoplastic. The crystal clear product has excellent thermal and dimensional stabilities, high flexural and tensile strengths, and good electrical properties. Rubber-modified types have been developed with superior impact properties for appliance, packaging, and housewares markets where abuse resistance is needed. Copolymers containing acrylonitrile have been marketed for applications, that require improved chemical resistance. Other types for phonograph records, sheets, and films have been marketed. Very lightweight, rigid foams have been developed and marketed for use in insulation, packaging of breakable items, and as molded items where lightweight and buoyancy are desired. The cost of polystyrene is low.

The past and projected growth of polystyrene production is as follows:

Year	Production, 10^9 lb/yr
1962	1.25
1963	1.50
1965	1.90
1967	2.25
1970	3.15
1977	4.40

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

The fundamental manufacturing process for polystyrene resins and copolymers is a batch process that uses a combination of both bulk (mass polymerization) and suspension polymerization methods. Styrene monomer, or mixtures of monomers, is purified by distillation or caustic washing to remove inhibitors. The purified raw materials, along with an initiator, are charged into stainless-steel or aluminum polymerization vessels. These vessels are jacketed for heating and cooling and contain agitators. Polymerization of the monomer is carried out at about 90°C to approximately 30% conversion. At this stage, the reaction mass is syrupy. During this prepolymerization step in the manufacturing process, water is used only as a heat-exchange medium. It does not come into contact with the product and is therefore not contaminated. This cooling water is recirculated.

The prepolymer, or partially polymerized mass, is then transferred to suspension polymerization reactors containing water and proprietory suspending and dispersing agents. The reactors are usually jacketed, stirred stainless-steel vessels and range in size from 1,000 to 5,000 gal. The syrupy mass is broken up into droplets by means of the stirrer and held in suspension in the aqueous phase. Temperature is a critical variable in the further polymerization of the product. After completion of polymerization, the polymer suspension is sent to a blow-down tank where any unreacted monomer is stripped. The stripped batch is then centrifuged, and the polymer product is filtered, washed, and dewatered (dried). A flow chart for this process is shown in Figure 5.

A few polystyrene producers eliminate the first step in this process and introduce purified monomer directly into the suspension polymerization reactor. Polymerization is thus carried out entirely via suspention polymerization.

B. Significant Water Wastes

Reaction water (suspension medium) and wash water constitute the two significant sources of waste water in the production of polystyrene. Some cooling water is lost due to evaporation, however, the amount lost is insignificant, compared to the primary sources of water waste.

Approximately 1.5 gal of water other than cooling water is used for each pound of polymer product produced. The thermal and chemical pollution of the effluent water is at a low level. This is due to the small quantities of additives used in suspension polymerization: (a) catalyst, 0.1 to 0.5% based on weight of monomer; (b) suspending agents, 0.01 to 0.5% based on weight of monomer; and (c) reaction medium temperature, 120 to 180°F. Although specific additives are proprietary, the catalysts used are generally of the peroxide type. The suspending agents used are a wide variety. They can be methyl or ethyl cellulose, polyacrylic acids and their salts, polyvinyl alcohol and numerous naturally occurring materials such as gelatin, starches, gums, casein, zein, and alginates. Inorganic materials such as calcium carbonate, calcium phosphate, talc, clays, and silicates may also be present in effluent reaction water. Water vapor is said to be the only air-discharged waste.

C. Reuse of Process Water in 1964

Water used in the suspension polymerization and washing of polystyrene polymer is not commonly reused. Water used for cooling is essentially uncontaminated and is recirculated through cooling towers. The amount lost due to evaporation constitutes approximately 1%.

D. Industry Subprocess Mix

The fundamental combination bulk-suspension polymerization process is used for a number of reasons:

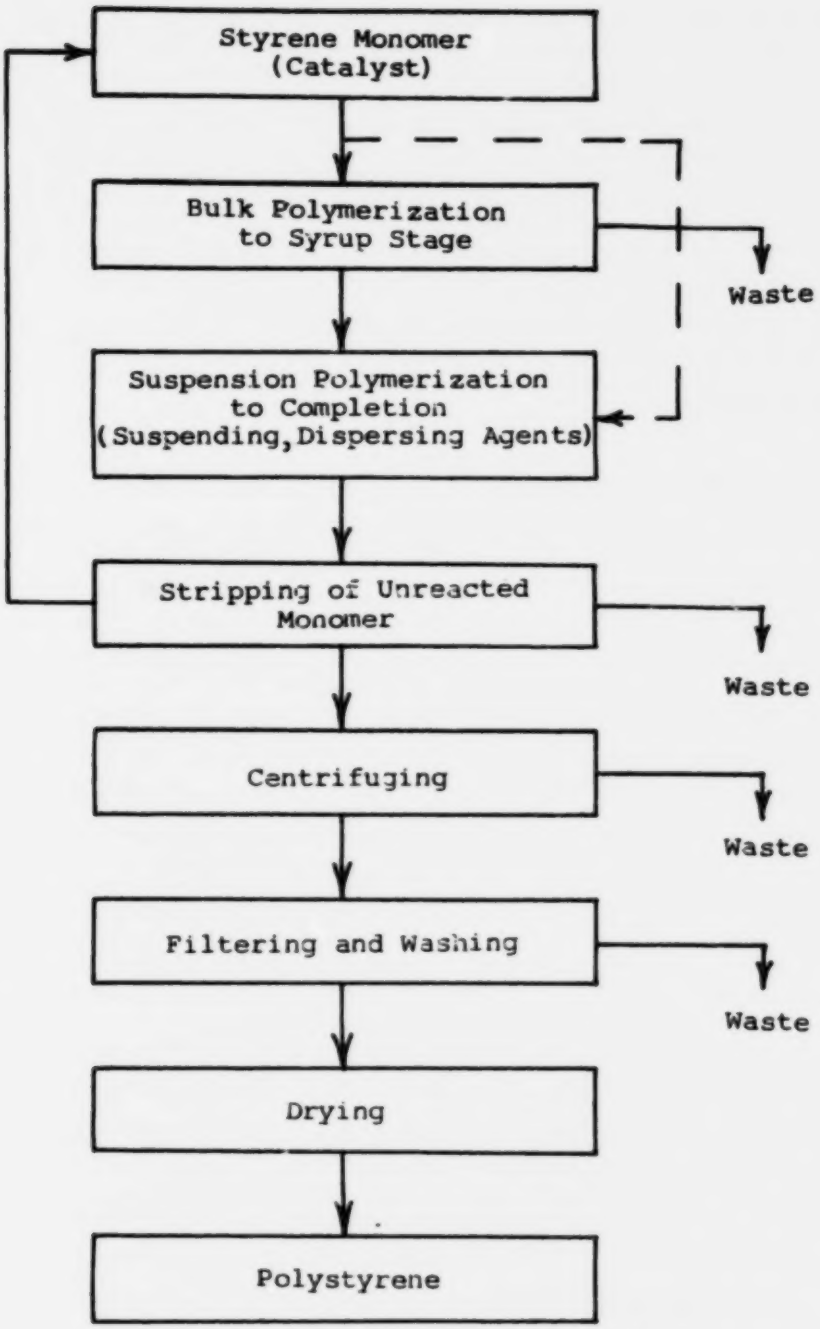

Figure 5
FLOW CHART FOR POLYSTYRENE PRODUCTION

(1.) It is the most economical, since water is used as the suspending medium and as a heat-transfer medium.

(2.) The product obtained is relatively pure and contains only trace amounts of catalyst and suspending agents, since only minimal amounts of these additives are used in the polymerization. Thus, purification of the product is usually unnecessary. Since this process is economical, efficient, and trouble-free with regard to waste problems, no new technology is foreseen. The companies interviewed intend to use present technology in the future. The level of technology therefore will have little effect on waste water content. However, since production will be increased over the next ten years, the volume of waste water, with incorporated wastes, will increase proportionally.

E. Difficult Waste Control Problems of Subprocesses

There are no subprocesses.

F. Levels of Technology

1. Typical

The combination bulk and suspension process is the typical level of technology.

2. Older

The present combination bulk-suspension polymerization of polystyrene is an outgrowth of the old "bead process." In the bead process, large monomer drops were suspension polymerized. Since large drops were used, the process was essentially a bulk polymerization and the problems associated with bulk polymerization were also inherent, namely, problems associated with mixing and heat transfer and broadening of molecular-weight range with subsequent lowering of mechanical properties. These difficulties were overcome in suspension polymerization by simply reducing the size of the drop being polymerized. Thus, in present technology, extremely small droplets of either monomer or prepolymer are utilized.

3. Advanced

Of the companies interviewed, only one anticipates converting to a new process. Details of the process were considered proprietary.

Technology Level	Range of Plant Size, 10^6 lb/yr	Plant Size, % Small 10-50	Medium 50-100	Large 100
Typical	10 to 100	20	30	50
Older	None	-	-	-
Advanced	None	-	-	-

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volumes for an Average Size Plant Producing 50 x 10^6 lb/yr

Waste Load, 10^6 lb/yr	Waste Water Volume, 10^6 gal/yr
0.5	75

No data could be obtained on the concentration of BOD or SS in waste water. The above waste load is based on the assumption that 0.5% suspending agents (based on the weight of product) are being used by the entire industry. It is possible that some products is lost in the waste water, but no data are available. A municipal treatment facility reported that the effluent from one polystyrene plant was entirely inorganic, indicating that no catalyst or product were present in the waste. No significant variations in loadings are caused by shift, daily, or seasonal changes. There are no significant differences in unit waste production for plants of significantly different production output.

B. Total Waste Quantities and Waste Water Volumes

Typical Technology	
Waste Quantities, 10^6 lb/yr	Waste Water Volume, 10^5 gal/yr
23	3.38

C. Total Waste and Waste Water Quantities/Unit of Physical Product

Typical Technology	
Waste Load lb/lb product*	Waste Water Volume gal/lb product
0.01	1.5

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year (1963)

Typical Technology	
Waste Load, 10^6 lb/yr	Waste Water Volume, 10^9 gal/yr
15.0	23

* Based on assumption that 0.01 lb of waste is produced per lb of product (0.5% catalyst plus 0.5% suspending agents); also assuming all of these contaminants are removed from product and disposed of in waste water and that no product is wasted.

E. Projected Gross Wastes and Waste Water Volumes

	Typical Technology	
	Waste Load,	Waste Water
Year	10^6 lb/yr	Volume, 10^9 gal/yr
1967	23	3.5
1968	25	3.8
1969	28	4.2
1970	32	4.7
1971	33	5.0
1972	35	5.3
1977	44	6.6

F. Seasonal Waste Production Patterns

There are no seasonal patterns in waste production from the polymerization of styrene-type plastics.

III. WASTE REDUCTION PRACTICES

A. Processing Practices

There are no processing practices associated with waste reduction.

B. Treatment Practices

1. Normal Removal Efficiency (%) of Waste Treatment Methods in a Plant Employing Typical Technology

No plants employing typical technology have waste treatment facilities.

2. Rate of Adoption of Waste Treatment Practices

Treatment has been and will continue to be discharged to municipal sewers at a rate exceeding 90%

(a) There are no sequential application or removal techniques required by technological considerations.

(b) There are no substitute techniques in use.

(c) There are no interdependencies among waste removal techniques that affect costs or relative efficiencies.

3. Combined Wastes

a. Percentage of Waste Discharged to Municipal Sewers

It is estimated that over 90% of the waste is discharged to municipal sewers.

b. Waste Removal Problems Caused by Combining Industrial with Municipal Wastes

Municipal water departments contacted in regard to problems they encounter with waste waters from the processing of polystyrene claim that to date no problems have arisen. Combination of this waste water with municipal wastes is feasible without alteration of existing treatment processes.

C. By-product Utilization

There are no by-product for wastes derived from the polymerization of polystyrene, and none is likely to be developed by 1977.

D. Base Year Net Waste Quantities

It is estimated that 15×10^6 lb of waste were discharged to municipal sewers in 1963. No accurate data on net amounts discharged, if any, to watercourses are available. At 87% for this particular type of waste, it can be estimated that 2×10^6 of waste reach the watercourse.

E. Projected Net Waste Quantities

No accurate data are available. It can be assumed that most of the waste will be discharged to municipal systems. Assuming that 87% removal will hold constant, the following net waste quantities can be estimated.

Year	Net Waste Quantities 10^6 lb/yr
1967	3.0
1968	3.3
1969	3.6
1970	4.2
1971	4.3
1972	4.6
1977	5.7

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facilities

Polystyrene plants studied* do not have waste removal facilities.

B. Capital Cost and Economic Life of Processing and Waste Removal Treatment Equipment

There are no waste removal treatment facilities.

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* The plants studied produce 80% of the polystyrene manufactured in the United States.

SECTION 4

SIC 28214 POLYOLEFINS

POLYETHYLENE

The polyethylenes produced today run the gamut from low-molecular-weight waxes of a few thousand-molecular-weight to polethylenes of several-million-molecular weight. In addition to the range in molecular weights, an equally wide range in stiffness is available. Product versatility is further obtained by synthesizing copolymers with hydrocarbons or polar monomers. To these qualities must be added low-cost, easy processability, good stability in processing, low permeability to water, good electrical properties, and wide range of property modification for specific processing or end use requirements. It is not uncommon for a producer to market more than 50 grades. In decreasing order of utilization polyethylene is used: film and sheet, injection molding, blow-molded bottles, cable insulation, coatings, pipe, and all other uses.

The past and project growth of polyethylene is as follows:

Year	Production 10^9 lb/yr
1962	1.85
1963	2.08
1965	3.03
1967	3.59
1970	4.95
1977	7.60

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

A fundamental process for manufacturing polyethylene is the high-pressure method.* For convenience, the final product is often referred to as low-density polyethlene (LDPE). This form of synthesis is an example of continuous-flow gas-phase bulk polymerization.** The high-purity (99.9%) ethylene stream is elevated to a process pressure and passed through a reactor in the presence of free radical initiators.

* For uniformity among manufacturers, the final product is defined by ASTM tests D151 or D792; Type I has a density between 0.914 and 0.925, Type II between 0.926 and 0.940

** Relatively small volumes of LDPE for specialty applications are commercially produced by solution and emulsion processes.

The resulting polymer-monomer mixture is seperated by pressure reduction into a monomer-rich stream and a polymer-rich stream. The monomer-rich stream can be cleaned and recyled as feed to the reactor or used in another process. The polymer-rich stream is usually further concentrated by a second separation step and then extruded into ribbons or strands for pelletizing.

The reactor can be of a tubular or an autoclave design. Figures 6 and 7 are the flow charts for these processes. The tubular reactor operates at 150 to 300°C between 14,000 and 40,000 psig* at the charge end and as low as 10,000 psig at the discharge end. The physical properties of the final product are a function of reaction temperature, pressure, equipment, and initiator or initiators. The autoclave polymerizes in minutes rather than seconds at a pressure between 15,000 and 30,000 psig. Modifiers can be added directly to the reactor or may be added to the feed stream before compression. Chain transfer agents, diluents, retarders, or accelerators can also be metered into the feed stream in an effort to modify reaction kinetics and polymer properties. The reaction mass at the end of the tube passes through a let-down valve into a product separator from which the polyethylene is removed, water-cooled, and chopped. The unreacted ethylene is cleaned, cooled, and recycled.

The high-pressure process can produce copolymers with polar materials, such as acrylates, as well as copolymers with olefins.

Another fundamental process for making polyethylene is the low-pressure method. The reaction product is referred to as linear, or high-density, polyethylene (HDPE).** The most common reaction is known as the Phillips process, which uses a supported catalyst (chromia-alumina combinations). A flow chart is shown in Figure 8. The reaction takes place in a low-pressure, agitated vessel between 135 and 190°C. The process utilizes solvent that must be separated and purified.

The other low-pressure method for synthesizing linear, or HDPE, is known as the Ziegler process (see Figure 9). The converter reactor and operating conditions are very similar to that of the Phillips process. The Ziegler process utilizes titanium halides and aluminum is used for catalysis.

The separation and purification of the solvent requires more sophisticated equipment than the Phillips process. In most respects the two processes and products are very similar.

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* Units have been operated between 9,000 and 70,000 psig.

** Linear polyethylene comes in densities between 0.940 and 0.970. Copolymers can be synthesized with other olefins.

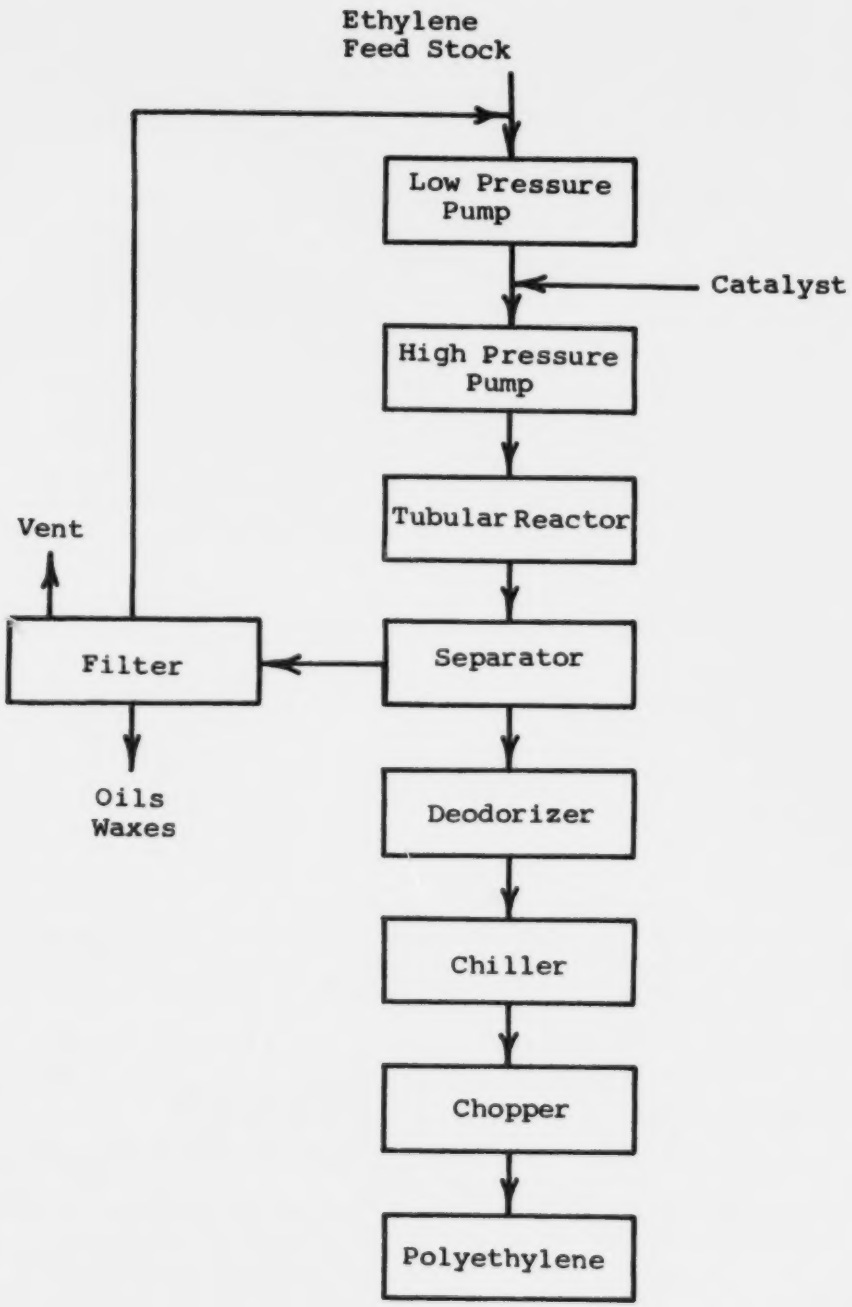


Figure 6

TUBULAR-REACTOR PROCESS FOR LOW DENSITY POLYETHYLENE PRODUCTION

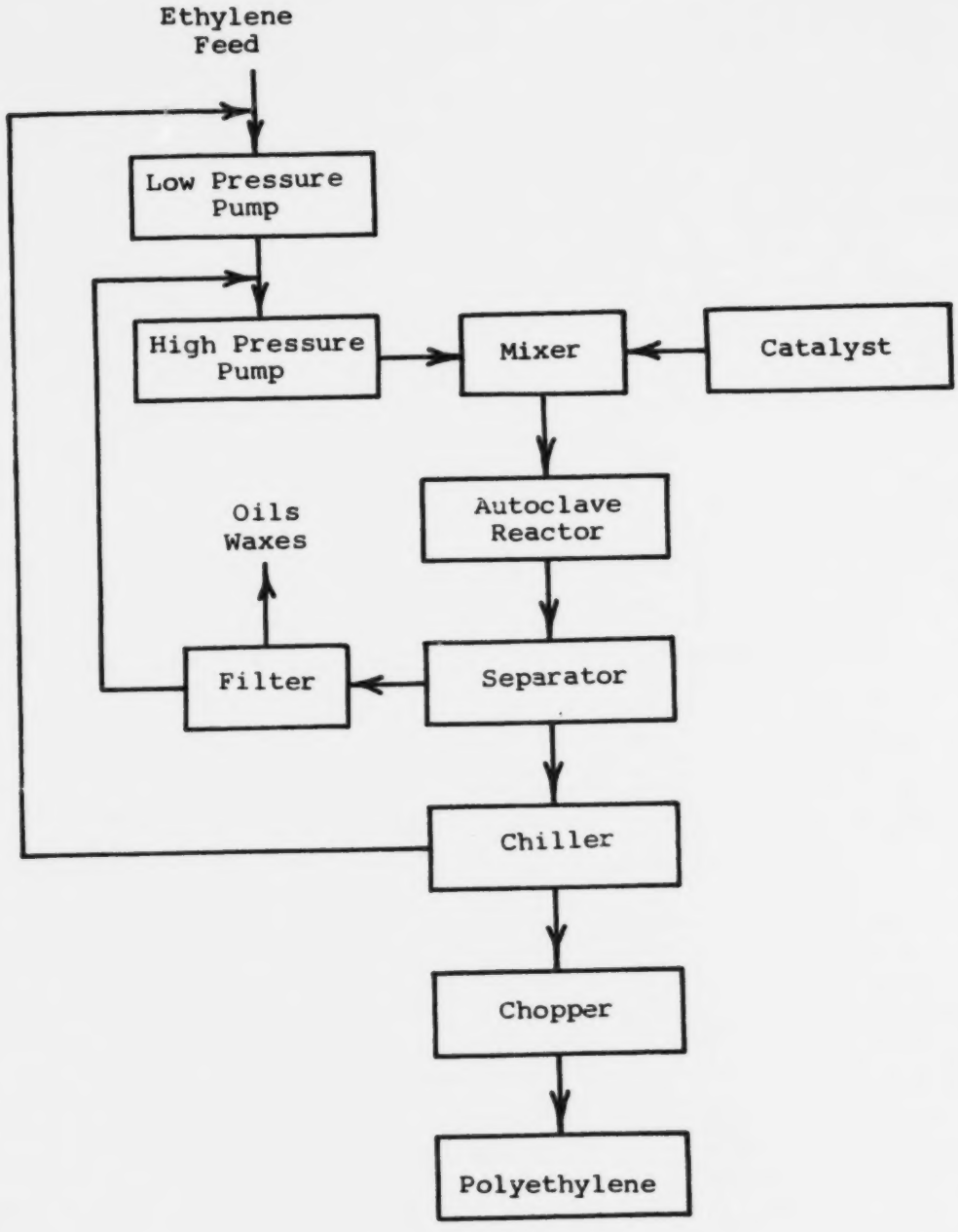


Figure 7

AUTOCLAVE-REACTOR PROCESS FOR LOW DENSITY POLYETHYLENE PRODUCTION

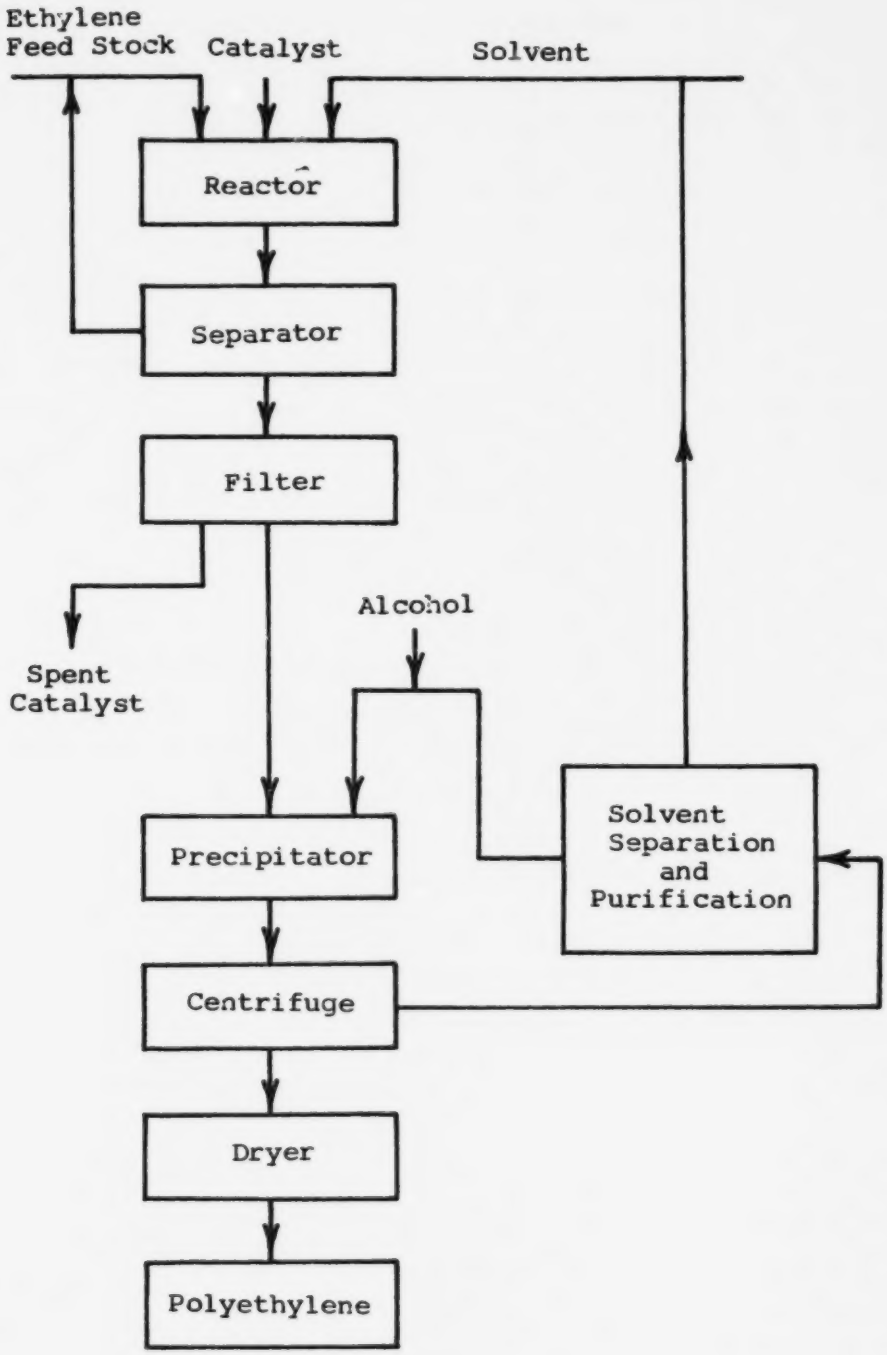


Figure 8

PHILLIPS PROCESS FOR HIGH DENSITY POLYETHYLENE PRODUCTION

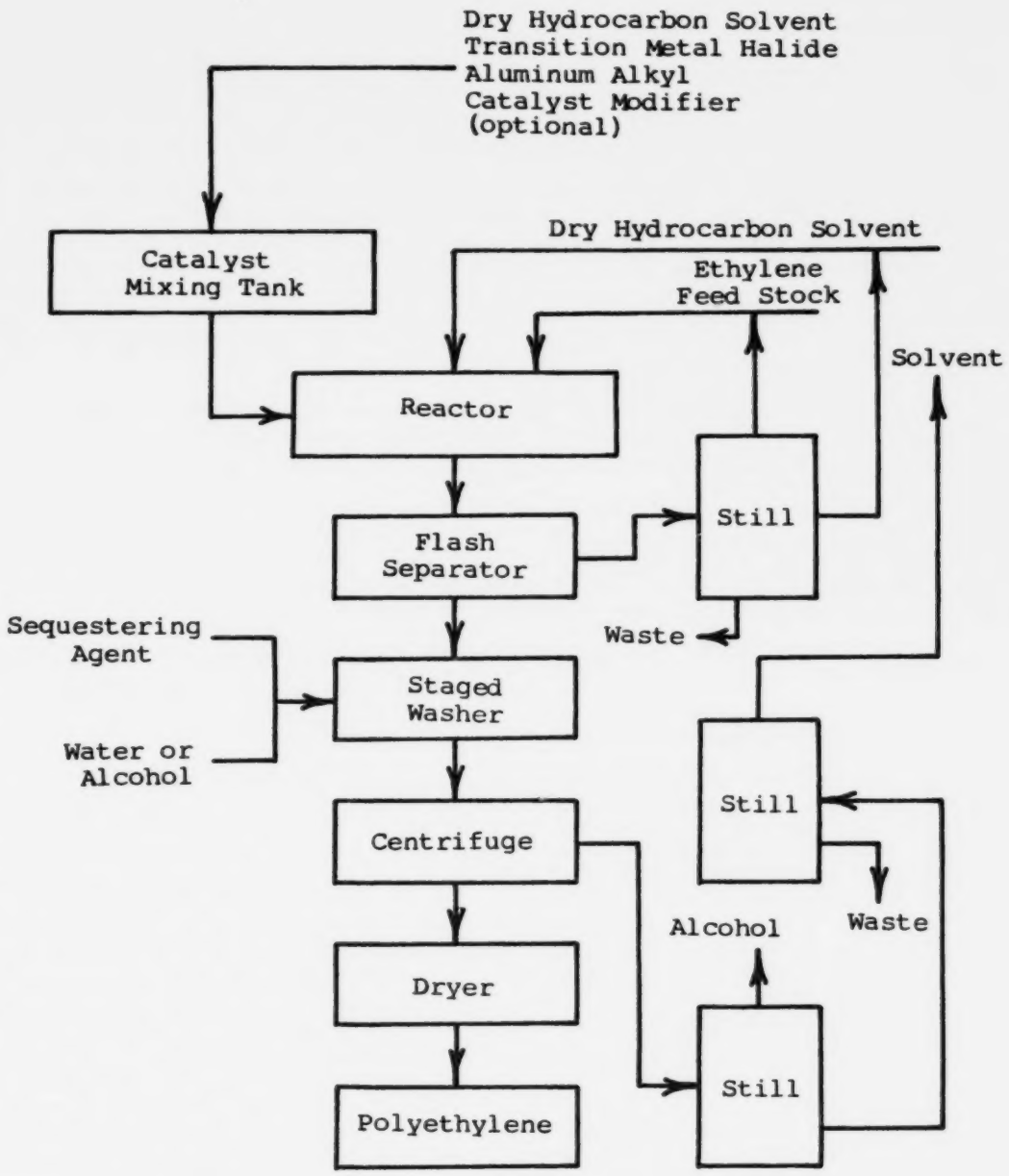


Figure 9

ZIEGLER PROCESS FOR HIGH DENSITY POLYETHYLENE PRODUCTION

B. Significant Water Wastes

Low-density polyethylene (LDPE) processes create no significant water wastes. Water contacts the product only at the chiller-chopper step. An analysis of a typical highly recirculated chill water (ribbon bath) revealed a very low total organic carbon (TOC) of 0.4 mg/liter.

The heat generation depends upon pressure, initiator concentration, and temperature. If the total conversion of ethylene were run adiabatically, the product temperature would be 1000°C hotter than the starting temperature. Heat is removed by loss through the tube walls and by removal through recycling of the gas and the product. These are properly balanced to give a stable system. As defined by current interpretation of legislation, thermal pollution is not a problem in polyethylene polymerization.

Air pollution is generated by the combustion of ethylene (flare gasses) that has been collected from accidental losses, valves, pumps, and fittings. Some plants burn solids wastes for power generation.

The high-density polyethylene (HDPE) processes, Phillips and Ziegler, produce no significant water wastes. Typical effluent process waste waters contain a BOD in the range of less than 10 mg/liter. Potential hazards for generation of waterborne wastes are improper operation, spills, and washdown of equipment and facilities.

Air-discharged wastes are generated from burning ethylene flare gas.

C. Reuse of Process Water in 1964

Water is used for chilling the final product (LDPE) at the time it is pelletized by dicers, choppers, or cube cutters. Alternately, die face cutters can be used to cut the molten polymer prior to chilling it. The volume of water utilized for this operation is insignificant, 4×10^6 gal/yr* for the entire LDPE industry.

It is customary to reuse the chill water with only minor makeup. The water is reused several hundred times. Because of the low volume involved, no accurate calculations have been made of this reuse.

Linear polyethylene (HDPE) uses approximately 150×10^6 gal/yr for process water.** In a typical operation water is not reused.

---

* A typical plant manufacturing 140×10^6 lb/yr of LDPE utilizes 200 gpm of chill water with 2% makeup. By assuming a total annual production of 2.9×10^9 lb of LDPE, we arrive at 4×10^6 gal/yr of process chill water.

** Calculations are based upon 1.05×10^6 lb HDPE produced per year; process water utilized at a rate of 144,000 gal per 10^6 lb of HDPE produced.

D. Industry Subprocess Mix*

Year	Estimated Percentage of Production from Process: High-Pressure Process	Low Pressure Process
1950	100	0
1963	78	22
1967	73	27
1972	70	30
1977	70	30

E. Difficult Waste Control Problems of Subprocesses

The volume of process water used and waste loads for fundamental processes and subprocesses and relatively insignificant. The variance found in waste loads between processes and between processes and subprocesses are relatively insignificant.

F. Levels of Technology

(1) Typical production processes are describred in Section IA.

(2) Older production processes are the same as the typical technology.

(3) No advanced technology is forseen.

Plant size **

		Plants	%
Small	(50×10^6 lb/yr)	12	39
Medium	($50\text{-}100 \times 10^6$ lb/yr)	11	35
Large	(100×10^6 lb/yr)	8	26

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volumes for an Average Sized Plant of 140×10^6 lb/yr of LDPE; and Average Sized Plant of 100×10^6 lb/yr of HDPE

The waste load for LDPE is insignificant and is too low for practical measurement.

---

* Data are interpolated and extrapolated from production data in pounds for years 1955, 1960, 1965, 1967, 1970, and 1975 from Plastics World, page 26, Jan. 1967.

** Chemical Profiles, 1 January 1965.

The waste water volume for LDPE is insignificant. There is no measurable flow.

A waste load of 12,000 lb BOD/yr is insignificant for HDPE.

A waste water volume of 144 x 10^6 gal/yr is insignificant for HDPE.

B. Total Waste Quantities and Waste Water Volumes

Waste load and waste water volume are insignificant for LDPE and HDPE.

C. Total Waste and Waste Water Quantities per Unit of Physical Product

Waste load and waste water volume are insignificant for LDPE and HDPE.

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year 1963

Waste load and waste water volume were insignificant for LDPE and HDPE.

E. Projected Gross Wastes and Waste Water Volumes

For both LDPE and HDPE, the waste load and waste water volumes are considered negligible for the years 1968 through 1977.

F. Seasonal Waste Production Patterns

There are no significant seasonal patterns in waste production.

III. WASTE REDUCTION PRACTICES

A. Processing Practices

1. Waste Reduction Efficiency (%) of a Given Subprocess Relative to Altemative Subprocesses

This is not applicable to polyethylene production.

2. Sequential Requirements and Intedependencies of Processes Affecting Waste Production

This is not applicable to ethylene production.

B. Treatment Practices

Waste loads and waste water volumes for LDPE and HDPE are so low that they do not require treatment. It is not expected that this condition will change in the future.

C. By-product Utilization

There are no by-products.

D. Base Year Net Waste Quantities

Base year net waste quantities were insignificant.

E. Projected Net Waste Quantities

Net waste in the future will be insignificant.

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facilities (1966)

Waste loads and waste water volumes are such that they do not require treatment for LDPE and HDPE.

B. Capital Cost and Economic Life of Processing and Waste Removal Treatment Equipment

Waste loads and waste water volumes are such that they do not require treatment for LDPE and HDPE. There are no reductions in processing costs due to modified technology or by-product recovery.

Source Material:

"Manufacture of Plastics," Vol. 1, W. Mayo Smith, Reinhold Publ. Corp., 1964.

"Polyethylene," R. A. Raff & J. B. Allison, Koppers Co., Inc., Interscience Publishers, 1956.

"Market Study of the Plastics Industry," R. Kirkconnell, 1963. Majority of data obtained by interviews, plant inspections, telephone communications, and in-house experience.

POLYPROPYLENE

Polypropylene is attractive for many uses because of its unique combination of desirable properties and low cost. These qualities make this polymer valuable in various molding and extrusion applications; special grades are also available for manufacture of film and fiber. It is amenable to use in injection-molding, blow-molding, and extrusion. High melting point and heat resistance go hand in hand to produce molded articles that withstand boiling and autoclaving, but have useful strength at elevated temperatures. Good machinability permits threading and/or the cutting operations on molded pieces. Its use for bread wrap and similar food-packaging applications is made possible by its non-toxic nature, low extractibles, and amenability to protection by stabilizers safe for food use. Polypropylene fiber and filament take advantage of the relatively high melting temperature and the high tensile strength that results when propylene is stretched. The polymer has found early use in pipe and sheet.

The pasts and projected growth of polypropylene reflects the management of desirable physical properties with low cost.

Year	Production 10^9 lb/yr
1962	0.15
1963	0.20
1965	0.37
1967	0.76
1970	0.90
1977	1.50

I. PROCESSES AND WASTE

A. Fundamental Manufacturing Process

The fundamental process for producing polypropylene involves polymerization, purification, and finishing. During polymerization, a solution of propylene in an inert hydro carbon diluent is converted to a slurry containing insoluble, crystalline and noncrystalline polymer of high molecular weight. The noncrystalline polypropylene formed in the process, along with catalyst and diluent, is separated from the crystalline pr duct during purification. The dried powder is then compound for specific end uses, pelletized, and packaged for shipment.

During polymerization, complete conversion of propylene per pass is not economically desirable. A fraction of the propylene must therefore be recycled. Certain impurities tend to accumulate and must be removed. Propane gradually builds up and must be distilled out.

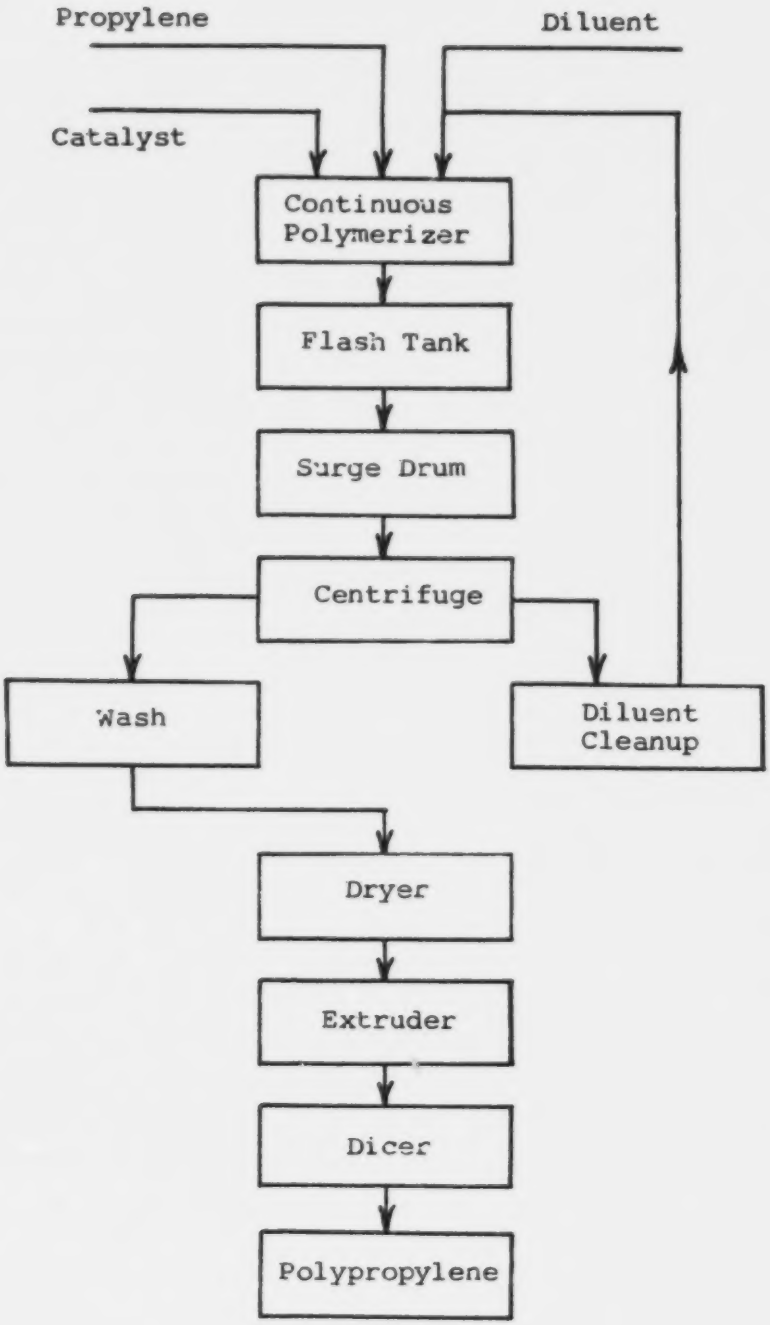


Figure 10

CONTINUOUS PROCESS FOR POLYPROPYLENE PRODUCTION

Polar materials used in the purification steps must be completely removed by distillation and/or suitable scrubbers or absorbers. Hydrocarbon diluent, which tends to be carried out with the propylene, may have to be removed, depending upon the process.

The process for the synthesis, purification, and finishing of polypropylene is a secret closely guarded by all manufacturers. However, well-recognized basic requirements and steps in the process have been published and can be taken as typical of existing conditions. The polymerization step may be either batch or continuous, both are in use. Figure 10 is a flow chart for the continuous process. The reaction takes place in vessels able to withstand 200 psig. Polymerization is exothemic (1000 BTU/lb of polymer). A part of the heat may be dissipated by cold incoming monomer and solvent in the continuous operation. Other methods of heat removal include jacket cooling, reflux condensers and re-circulation of cool slurry.

B. Significant Water Wastes

The synthesis of high-density polyethylene (HDPE) and polypropylene presents very similar processes, waste loads, and waste water volumes. In both cases, the loads and volumes present almost negligible problems relative to treatments and costs.

SECTION 5

SIC 28215 ACRYLICS

The acrylic monomers are mainly used in the preparation of polymers and copolymers of increasingly broad application. Several producers make cast sheet. The volume has increased with price reduction. During the past few years, the production of emulsion products (paints) has increased sharply.

The acrylic monomers are commercially polymerized by a free radical process.

Year	Production, 10^9 lb/yr
1962	0.18
1963	0.20
1965	0.24
1967	0.29
1970	0.37
1977	0.52

I. PROCESS AND WASTES

A. Fundamental Manufacturing Process

Acrylic resins are made by three processes: bulk polymerization, solution polymerization, and emulsion polymerization. Bulk polymerization is used for cast sheets and molding and extruding powders. Solution polymerization is used for industrial sales coatings including automobile paints and fabric coatings. Emulsion polymerization is used mainly for trade sales coatings such as home paints. A good estimate is that about 40% of acrylic resins are made by emulsion polymerization.

Emulsion polymerization of acrylic resins is a batch operation. The monomer is combined with the catalyst, water, and surfactant in a large vat. Polymerization and emulsification are carried out simultaneously. Some of the water is removed and additional surfactant added. Lumps are removed by either filtration or centrifugation, and the emulsion is placed into storage. The final product contains about 50% acrylic resin. This process is a batch process, and efficient operation requires vats that are no smaller than 1000 gal. A maximum size of 4000 gal results from a need to control the progress of the polymerization and remove the heat of reaction.

Figure 11 is a flow diagram of the emulsion process.

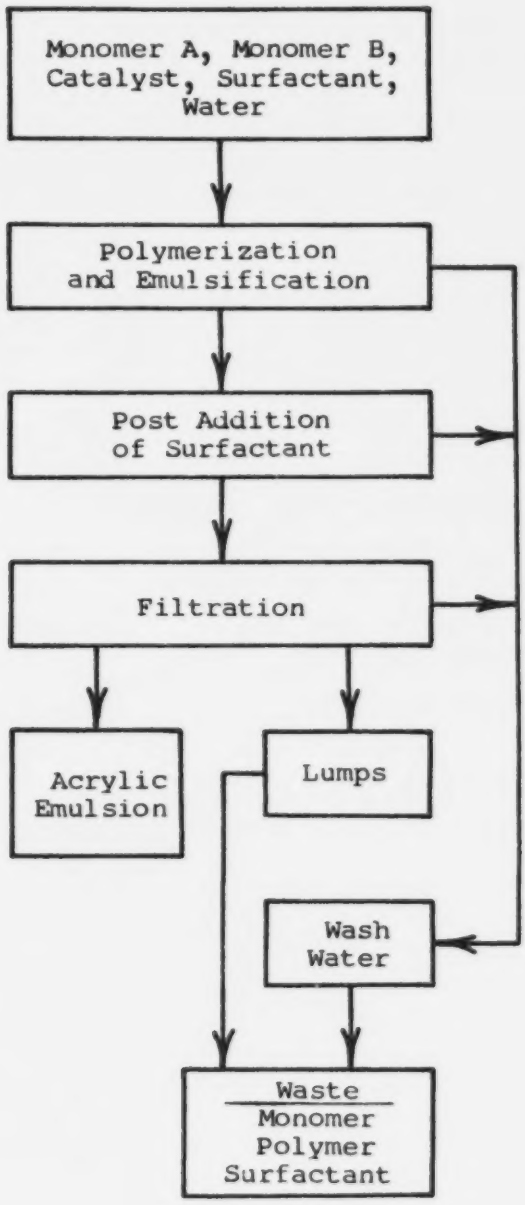


Figure 11

FLOW DIAGRAM FOR THE PRODICTION OF ACRYLIC EMULSION

B. Significant Water Wastes

1. Emulsion Process

The bulk and solution polymerization methods create very little wastes. Waste from the manufacture of acrylic resins is virtually all from emulsion polymerization. The emulsion polymerization process will be considered the fundamental process since waste is the main concern in this study.

The emulsion polymerization of acrylates creates a concentrated water waste. The waste in the process comes from washing the vat between batches and from lumps that are filtered or centrifuged out of the emulsion mix. Thus the waste contains acrylic monomer, acrylic polymer, emulsifying agents, and catalyst.

The waste is white and highly turbid and has a high suspended-solids content.

2. Other Acrylic Processes

There is no known process water involved in the polymerization of acrylates by the other two processes.

C. Reuse of Process Water in 1964

There is no reuse of process water.

D. Industry Subprocess Mix

There is some subprocess mix by those who make acrylic emulsions. Both the products of the emulsion process and the solution process are mainly directed towards the coatings market. Thus the manufacturer of emulsions very often has a solution acrylic product as well. Usually less than 20% of the acrylic volume is the solution type. The product mix also includes a number of other coating products so that very little of the total combined waste is due to the manufacturer of acrylic resins.

E. Difficult Waste Control Problem of Subprocesses

Very little waste is created by the subprocesses. There are no difficult waste control problems from them.

F. Levels of Technology

1. Typical

All three methods -- emulsion, solution, and bulk -- must be considered typical methods for making acrylic resins. Since the uses are

different, they are not competing for the same market, and the production in one area does not affect the market in another. Jointly, they affect one another only in the demand for the monomer.

2. Older

The oldest process is the bulk polymerization process, but the demand for the bulk material has not been affected by the markets for the other two types of acrylic resins.

3. Advanced

An advanced type of acrylic resin has been developed recently. It is called a syrup and consists of a solution of polymer in the monomer. It has special advantages in bulk-type applications, i.e., for making sheets and complicated solid shapes. Its waste should be little different from that of the bulk-type operation. Perhaps the ease in its use will improve the market for the bulk resin. This technology is considered proprietary; consequently, accurate projections cannot be made.

No reliable data are available for the range of plant sizes and outputs.

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volumes for One Plant Current Technology - Medium Sized Plant

	Waste Load, 10^6 lb BOD/yr	Waste Water Volume, 10^9 gal/yr
Emulsion (20 x 10^6 lb/yr)	0.030	0.0025

There is no significant difference in unit waste production for plants of significantly different production output.

B. Total Waste Quantities and Waste Water Volumes

	Waste Load, 10^6 lg BOD/yr	Waste Water Volume, 10^9 gal/yr
Emulsion	0.165	0.014

C. Total Waste and Waste Water Quantities per Unit of Physical Product

	Waste Load, lb BOD/lb Prod	Waste Water Volume, gal/lb
Emulsion	0.0015	0.125

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year 1963

	Waste Loac, 10^6 lb BOD/yr	Waste Water Volume, 10^9 gal/yr
Emulsion	0.120	0.010

E. Projected Gross Wastes and Waste Water Volumes

Emulsion Polymerization

Year	Waste Load, 10^6 lb BOD/yr
1968	0.192
1969	0.204
1970	0.222
1971	0.234
1972	0.252
1977	0.312

F. Seasonal Waste Production Patterns

For most manufacturers of acrylic resins, a seasonal pattern does not exist. For the emulsion manufacturer directly tied into trade sales of paint, the manufacturer leads the trade sale by 60 days. The fall and winter months are the slowest for paints; demand may drop as much as 30% during these months.

The amount of the acrylic resins being used for latex paints is somewhat less than 40% of the total resin output. The amount of future seasonal changes will depend on the demand for acrylic latex paints. Although the paint is easy to apply and weathers well, it is expensive.

III. WASTE REDUCTION PRACTICES

A. Process Practices

1. Waste Reduction Efficiency (%) of a Given Subprocess Relative to Alternative Subprocesses

Although still an undisclosed quantity, the wastes related to the bulk process and to the solution process are reputed to be insignificant,

compared to the waste from the emulsion process. Comparisons between subprocesses are invalid, however, since the products do not compete with each other for the same end use.

2. Sequential Requirements and Interdependencies of Processes Affecting Waste Production

An accurate answer to this question cannot be given at this time.

B. Treatment Practices

1. Normal Removal Efficiency (%) of Waste Treatment Methods in Treating Waste from a Plant of Typical Technology

Acrylic plants, unlike cellulosic plants, are in a complex of facilities that make a number of different products with a corresponding variety of wastes. Also, the acrylic plants generally feed their waste into municipal systems. This has created a number of problems from the start and a variety of eventual solutions. These solutions range from a self-contained closed-end waste treatment plant in which the water is continuously recycled to a wash water treatment plant that also treats the waste for a municipality in a joint operation.

A particular plant, where some waste removal efficiency data were available, uses activated sludge. The removal efficiency of BOD is 85%. Suspended solids removal was estimated to be at about the same level.

2. Rate of Adoption of Waste Treatment Practices

No concrete data of this type were available, but it is apparent that everyone either had a treatment facility or was about to install a treatment facility that would meet the requirements of the present local code.

3. Percentage of Waste Discharged to Municipal Sewers

No data of this type were available.

4. Waste Removal Problems Caused by Combining Industrial Waste with Municipal Wastes

The waste is white, highly turbid and has a high suspended solid content. By nature, the waste requires a particularly long biodegradation time. A 14 to 20 day treatment is being used in one plant. In another plant the suspended solids are passed directly into a settling pond where they are precipitated with fly ash generated in the heating plant. This process does not take care of all of the fly ash, but it seems to be the solution to the suspended solids problem.

The waste is better treated at the plant to remove the suspended solids before passing the effluent out into a municipal system. Some municipal plants have reported these wastes as essentially untreated under standard operating conditions.

C. By-product Utilization

There are no by-product uses of wastes not is there a likelihood of any being developed and marketed in the next ten years.

D. Base Year Net Waste Quantities

No data are available that would permit calculation of net waste quantities reaching watercourses in 1963. They are no greater than the gross quantities and probably no less than 10% of those figures.

E. Projected Net Waste Quantities

No data are available to permit calculations of projected net waste quantities.

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facilities (1966)

Data in this specific format (replacement value) were not available. The following figures give some indication of treatment costs.

Emulsion produced	0.0037 $/lb Product (Emulsion)
Total acrylics produced	38×10^3 $/yr
Capital goods depreciation	33×10^3 $/yr
Operating and maintenance	5×10^3 $/yr

B. Capital Cost and Economic Life of Processing and Waste Removal Treatment Equipment

	Capital Depreciation, $/lb product	Economic Life, yr
Emulsion	3×10^{-4}	40

Capital goods cost for total acrylics produced* = $\$1.3 \times 10^6$.

* Total waste comes from the production of acrylic emulsion.

SECTION 6

SIC 28216 ALKYD AND POLYESTER RESINS

Alkyds and polyesters are characterized by great variation in formulations, not only as represented by the class of resin produced, such as oil-modified polyesters (alkyds), unsaturated polyesters (laminates and molding compounds), and linear polyesters (films and fibers), but also within each group. For example, one plant engaged solely in the production of alkyd resins had 300 different compositions in active manufacturing status. Saturated polyesters are used for urethane plastic production. Highly branched polyesters are used for urethane polymers for coatings, rigid foams, and adhesives.

Many of the applications for polyesters require a cross-linking (curing) process that is difficult to control and does not lend itself to mass production; the anticipated growth rate reflects some of these processing characteristics.

Year	Production, 10^9 lb/yr
1962	0.68
1963	0.76
1965	0.92
1967	1.10
1970	1.40
1977	1.80

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

The fundamental manufacturing process for alkyd and polyester resins is batch-type condensation polymerization of a dibasic acid and a polyfunctional alcohol. Polymerization in the presence of oils or fatty acids results in a complicated polymer known as an alkyd resin. The polymerization process is illustrated in Figure 12. Two types of polyester resins can be identified. One consists of an unsaturated polyester to which a monomer is added, e.g., styrene, resulting in thermosetting properties due to copolymerization. The other, a simpler polymer, consists of linear chains with no provision for cross-linking. In each case the raw materials are heated to the reaction temperature (165 to 260°C) and the degree of polymerization is monitored by viscosity or acid number.

B. Significant Water Wastes

The significant wastes associated with the production of alkyd and polyester resins are (1) unreacted volatile fractions of raw materials that either appear in the withdrawn water of esterification and in the water used in scrubbers, or are vented to the atmosphere, and (2) residue in kettles cleaned out either with caustic solutions or solvents.

C. Reuse of Process Water in 1964

In the representative segment of the industry studied, no significant amount of process water is reused.

D. Industry Subprocess Mix

No subprocesses in the polymerization of alkyds and polyesters were encountered. Production technology has been stable, and the consensus is that it will remain so.

E. Difficult Waste Control Problems

The variation in the attitude of the plant toward the difficulty of waster control is illustrated by the differences in waste water treatment practices. These practices vary from no treatment to complete segregation and shipping out of all process waste water in tank trucks for land disposal since no treatment facilities exist.

F. Levels of Technology

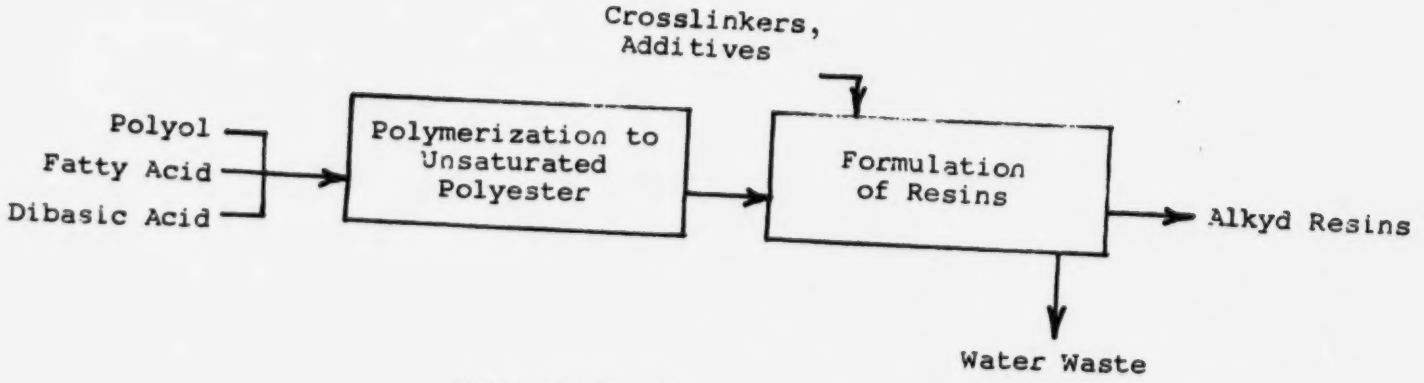
No distinction between levels of technology could be identified.

Plants range in size from 1 to 30 million lb/yr. No estimate of percentages of small, medium, and large plants is available.

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volumes for an Average Size Plant Producing 10×10^6 lb/yr

Production	10×10^6 lb/yr
Waste load	55×10^3 lb/yr
Waste water volume	20×10^5 gal/yr



FLOW CHART FOR ALKYD PRODUCTION

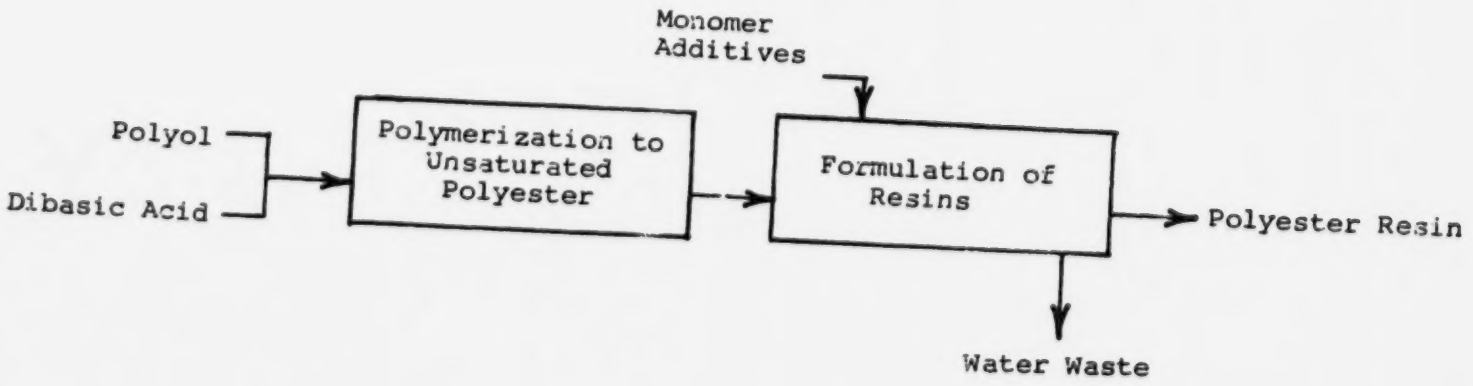


Figure 12
FLOW CHART FOR POLYESTER PRODUCTION

The waste load is predominately solvent or caustic kettle residue -- cleaning solution. Unit waste production does not vary significantly for plants of substantially different production output.

Waste water volume can vary considerably, however, depending on whether scrubbers are used to control vapors from the process. The above table assumes the use of scrubbers.

Loading is of course sporadic since a batch process is involved and washout is the significant source of waste. Variation in loading on a time scale greater than a day, however, is not encountered.

B. Total Waste Quantities and Waste Water Volumes

Waste load	6.6×10^6 lb/yr
Waste water volume	2.3×10^9 gal/yr

C. Total Waste and Waste Water Quantities per Unit of Physical Product

Waste load	0.006 lb/lb product
Waste water volume	2.0 gal/lb product

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year 1963

Waste load	4.6×10^6 lb/yr
Waste water volume	1.52×10^9 gal/yr

E. Projected Gross Waste and Waste Water Volumes

Year	Waste Load, 10^6 lb	Waste Water, 10^9 gal
1968	7.5	2.5
1969	7.8	2.6
1970	8.4	2.8
1971	8.7	2.9
1972	9.0	3.0
1977	10.8	3.6

This projection is based on production data for the years 1962 to 1967 and on the estimated growth rate.

F. Seasonal Waste Production Patterns

There are no significant seasonal patterns in waste production.

III. WASTE REDUCTION PRACTICES

A. Processing Practices

1. Waste Reduction Efficiency (%) of a Given Subprocess Relative to Alternative Subprocesses

There are no subprocesses.

2. Sequential Requirements and Interdependencies of Processes Affecting Waste Production

There are no sequential requirements or interdependencies.

B. Treatment Practices

Three degrees of treatment are practiced.

1. No Treatment

A small plant of relatively low production volume may discharge process water directly into the watercourse, perhaps through a leaking bed. Some plants discharge into municipal systems.

2. Nominal Treatment

Large plants isolate process water and put it through step tanks where oils, etc. are removed by flotation and a solvent isolation process where some solvent is recovered for reuse. The effectiveness of these treatment processes is not known, but it is unlikely to be high.

3. Land Disposal

One plant, rather than treat process water, collected it in tank trucks and hauled it away for land disposal. It is maintained here that no adequate treatment process exists for waste water from polyester production. This method is undoubtedly effective in reducing the waste load in the plant effluent, but the ultimate history of the disposed waste is not known.

4. Rate of Adoption of Waste Treatment Practices

No data were available. Some plants indicated installation of vapor control in the early 1960s. The extent to which this has affected water pollution is unknown.

5. Combined Wastes

a. Percentage of Wastes Discharged into Municipal Sewers

Approximately 50% of the waste load is discharged to municipal sewers.

b. Waste Removal Problems Caused by Combining Industrial with Municipal Wastes

There are no problems that have been attributed to this waste.

C. By-product Utilization

No by-products are utilized to reduce waste loads. Solvents are partially removed from wastes for reuse, thus reducing the waste load. Development of new by-products is unlikely.

D. Base Year Net Waste Quantities

Estimated net waste quantitites reaching watercourses in 1963 is 3×10^6 lb.

E. Projected Net Waste Quantitites

No data are available.

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facilities (1966)

Treatment cost*	181×10^3 \$/yr
Capital goods depreciation	8×10^3 \$/yr
Operating and maintenance	18×10^3 \$/yr

No one interviewed or visited used any other treatment method, and the above were found only in plants with relatively large production. Unit cost would undoubtedly be higher in a smaller plant.

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* Sewer charges for 1.1×10^9 gal/yr at \$113/10^6 gal; primary treatment for 132×10^6 lb product at 2×10^{-4} \$/lb product; and 7.7×10^6 lb product at 4×10^{-3} \$/lb product for land disposal.

B. Capital Cost and Economic Life of Processing and Waste Removal Treatment Equipment

Capital goods cost*	$8 x 10^3
Economic life	20 yr

There are no reductions in processing costs due to modified technology or by-product recovery.

* Sewer charges for 1.1×10^9 gal/yr at $\$113/10^6$ gal; primary treatment for 132×10^6 lb product at 2×10^{-4} \$/lb product; and 7.7×10^6 lb product at 4×10^{-3} \$/lb product for land disposal.

SECTION 7

SIC 28217 UREA AND MELAMINE RESINS

Urea and melamine resins which can be used interchangeably, compete with phenolics. Quality and economic considerations dictate the choice. The products are water white, allowing pastel shades for items requiring aesthetic qualities. Their superior tensile and modulus command a higher price over phenolics. Their electrical properties are outstanding. These products can be manufactured interchangeably in phenolic process equipment. In some cases, water treatment charges overlap.

A modest growth rate is reflect in the following:

Year	Production, 10^9 lb/yr
1962	0.49
1963	0.51
1965	0.59
1967	0.66
1970	0.74
1977	0.95

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

The fundamental manufacturing process for urea and melamine resins is a batch condensation polymerization of the urea or melamine with formalin, a 40% solution of formaldehyde in water. The raw materials, urea or melamine and formalin, together with catalysts, miscellaneous additives, and modifiers of a proprietary nature, are charged into a jacketed reaction vessel and heated to initiate the reaction. Once initiated, the reaction is exothermic, and the heating steam is shut off. Cooling water is introduced into the jacket to control the reaction temperature. The mixture is refluxed until the proper degree of polymerization is reached. The resin is soluble in water so no separation occurs as in the case of phenolics-formaldehyde condensation resins. The urea and melamine resins are vacuum-dehydrated until the solids content is 50 to 60% and either sold as a solution or sprayed-dried and sold as a solid product. At the present time the market demand is 70% for the spray-dried product and 30% for the solution (60% solids).

Flow diagrams for the manufacturing processes are shown in Figures 13 and 14.

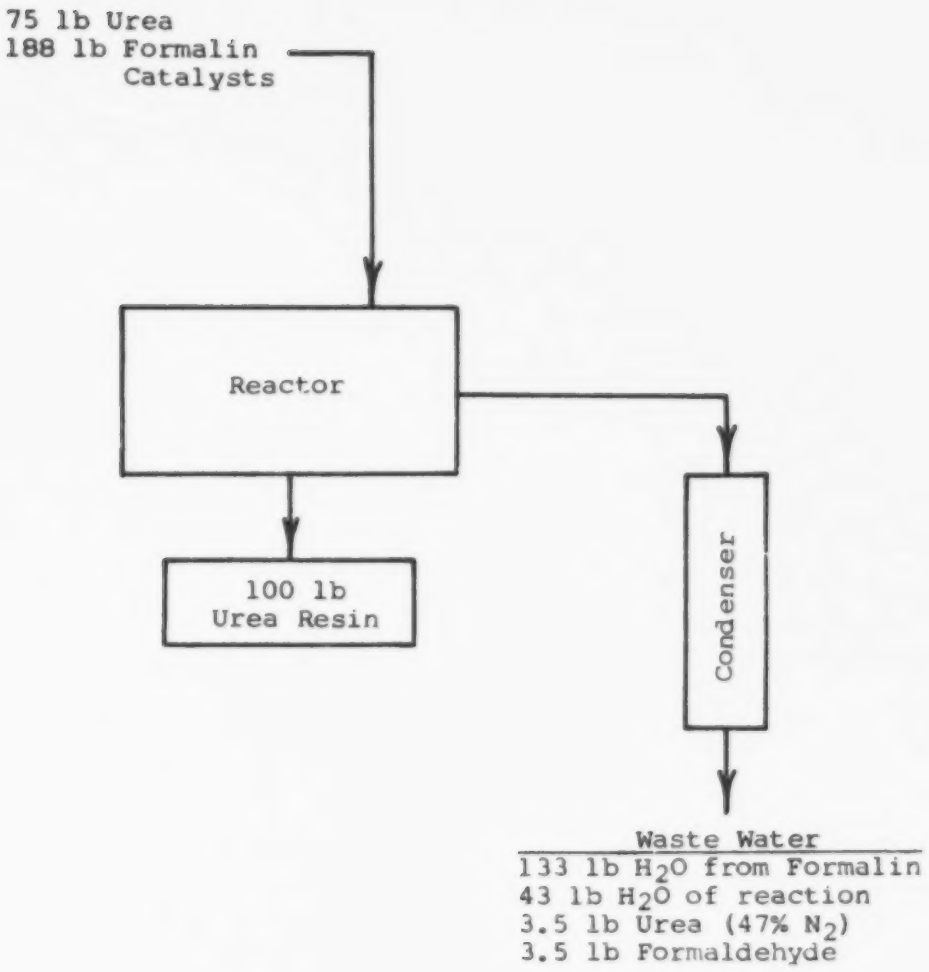

Figure 13

FLOW CHART FOR PRODUCTION OF UREA-FORMALDEHYDE RESIN

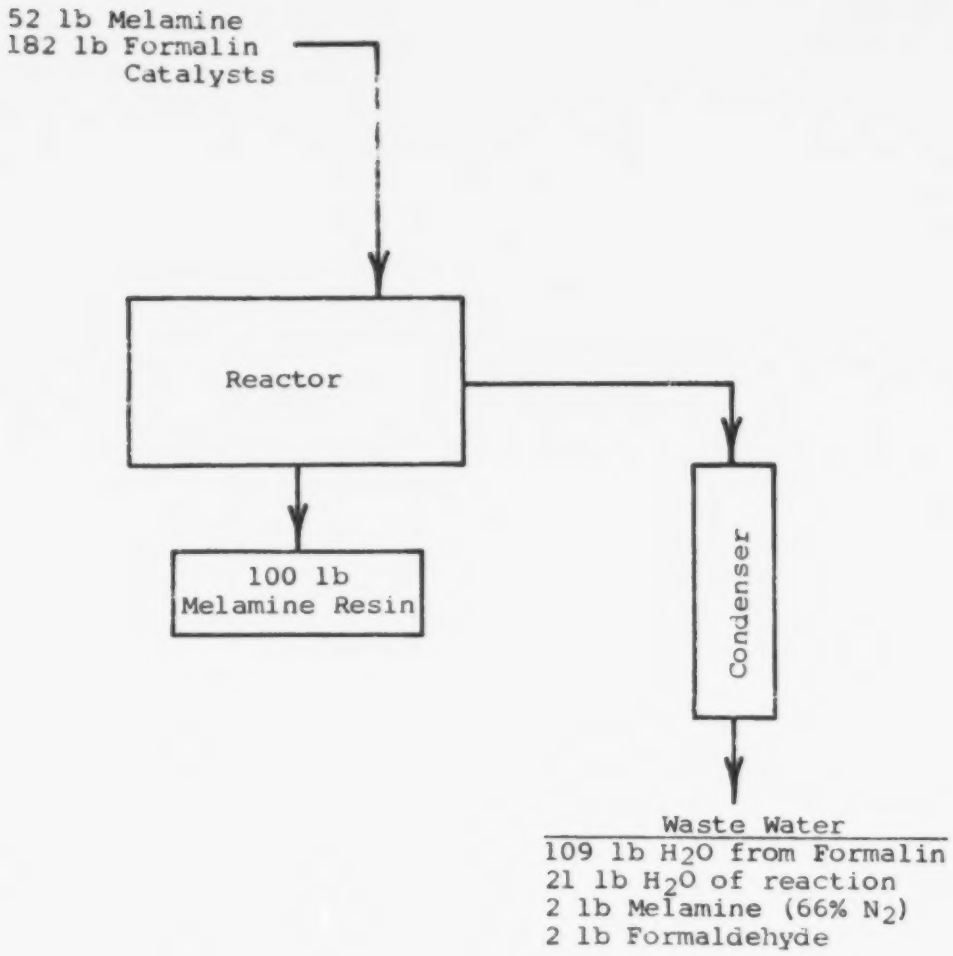

Figure 14

FLOW CHART FOR PRODUCTION OF
MELAMINE-FORMALDEHYDE RESIN

B. Significant Water Wastes

The significant water wastes from the production of urea and melamine resins are: water introduced with the raw materials, (2) water formed as a product of the condensation reaction, (3) caustic solutions used for cleaning the reaction kettles, and (4) blowdown fo from cooling towers. The first three wastes are termed process water, and the fourth is a portion of the cooling water required to control the reaction temperature.

From Figure 13, the volumes of these waste waters can be estimated. Per 100 lb of dry urea, 10.8 gal of process water is sewered, excluding the caustic cleaning solution. The cleaning solution is required only when the formulation per kettle is altered significantly. A reasonable estimate of usage, prorated over a year's production is 0.01 gal of a 2% sodium hydroxide solution per 100 lb of resin. About 240 gal of cooling water is required to control the reaction temperature. Of this amount, 17 gal is discharged to the sewers as cooling tower blowdown.

Per 100 lbs of dry melamine, 7.7 gal of process water is sewered, excluding the caustic cleaning solution. Cleaning solution requirements and cooling water needs are similar to the urea resins.

The waste water discharged from resin plants has a temperature of about 85 to 90°F. Thus, thermal pollution is not a problem.

Spray-drying of the resin solution can result in an air pollution problem. Generally, gas-fired driers are used, and the resin is dried by contact with heated air. The pollution, therefore, consists of constituents present in the fuel and small solids of product that are entrained in the air and carried out to the atmosphere.

C. Reuse of Process Water in 1964

Process water was not reused in 1964.

D. Industry subprocess Mix

Condensation polymerization is the only process used for producing urea and melamine resin. Production technology has changed little over the past 20 years, and no new "advanced" technology is foreseen. The level of technology has little effect on the waste water volumes and content.

If the resins were completely dehydrated by vacuum distillation, the process water discharged would increase by 7.9 gal per 100 lb of dry product.

E. Difficult Waste Control Problems of Subprocesses

There are no subprocesses.

F. Levels of Technology

The batch condensation polymerization technology is representative of "typical," "older," and "newer" subprocesses. No data are available on the proportion of small, medium, or large plants.

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OF OTHER DISPOSAL

A. Waste Quantitites and Volumes for an Average Size Plant Producing 10 Million lb/yr

	Waste Load, 10^6 lb/yr				
	BOD	SS	Urea or Melamine	Formaldehyde	Waste Water Volume, 10^6 gal/yr*
Urea	NDA	NDA	0.35	0.35	1.1
Melamine	NDA	NDA	0.20	0.20	0.77

There is no significant variation in unit waste production for plants of significantly different production outputs. There is no significant variation in loading by season. Because of the batch nature of the production, hourly variations can be expected.

B. Total Waste Quantities and Waste Water Volumes

See II-A, "Typical", "older", and "newer" technologies are similar.

C. Total Waste and Waste Water Quantities/Unit of Physical Product

	Waste Load, lb/lb product				
	BOD	SS	Urea or Melamine	Formaldehyde	Waste Water Volume, gal/lb
Urea	NDA	NDA	0.035	0.035	0.108*
Melamine	NDA	NDA	0.02	0.02	0.077*

* Process water only.

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year (1963)

	Waste Load, lb/yr				Waste Water Volume, gal/lb
	BOD	SS	Urea or Melamine	Formaldehyde	
Urea and melamine	NDA	NDA	13.8×10^6	13.8×10^6	47

These figures are based on the combined production of 510 million lb of urea and melamine resins.

E. Projected Gross Wastes and Waste Water Volumes

Year	Production, 10^6 lb/yr	Waste Load, 10^6 lb/yr			
		BOD	SS	Urea and Melamine	Formaldehyde
1968	680	NDA	NDA	18.3	18.3
1969	720	NDA	NDA	19.5	19.5
1970	740	NDA	NDA	20.0	20.0
1971	770	NDA	NDA	20.8	20.8
1972	800	NDA	NDA	21.6	21.6
1977	950	NDA	NDA	25.6	25.6

F. Seasonal Waste Production Patterns

There are no significant seasonal pattern in waste production.

III. WASTE REDUCTION PRACTICES

A. Processing Practices

1. Waste Reduction Efficiency (%) of a Given Subprocess Relative to Alternate Subprocesses

There are no subprocesses.

2. Sequential Requirements and Interdependencies of Process Affecting Waste Production

Each time a formulation is significantly changed, the kettle must be cleaned with caustic. Typically, 350 lb of 50% sodium hydroxide is added to a 4000-gal kettle and diluted to 2% with water. On the average, caustic wash is used after every 10 batches or on a monthly basis.

B. Treatment Practices

1. Normal Removal Efficiency (%) of Waste Treatment Methods in Treating Waste from a Urea and Melamine Plant of Typical Technology

Removal Method	Normal Removal Efficiency, % BOD	SS	Urea and Melamine	Formaldehyde
Lagooning	NDA	NDA	NDA	NDA
	Lagoons are constructed so that there is no overflow of water. Evaporation and seepage balance inflow. Lagoons can produce malodors and result in air pollution complaints.			
Thermal incineration	100	100	100	100
	Thermal incineration can cause air pollution, depending upon the fuel used and the efficiency of the oxidation process. Theoretically, the organic matter in the waste water is converted to carbon dioxide, water, and nitrogen oxides.			
Municipal sewage plant	NDA	NDA	NDA	NDA
	It is difficult to assign removal efficiency figures for resin wastes because they are mixed with many other wastes, including sanitary sewage.			

2. Rate of Adoption of Waste Treatment Practices

Reliable estimated can not be given because of the small sample size. Most plants, however, either employ lagoons or utilize a municipal sewer. Thermal incineration is not yet being used on melamine or urea waste waters.

a. There are no sequential applications of removal techniques required by technological considerations.

b. Final treatment can be accomplished by lagoons or treatment by a municipal sewage plant or by incineration.

c. There are no interdependencies among the waste removal techniques that affect costs or relative efficiencies.

3. Combined Wastes

a. Percentage of Waste Discharged to Municipal Sewers

The exact figures are unknown but direct discharge to a water course without treatment or with only quiescent settling was commonplace in the 1950s. Now, many plants discharge their wastes into a municipal sewer.

b. Waste Removal Problems Caused by Combining Industrial with Municipal Wastes

Municipal sewage authorities indicate a high degree of acceptance for urea and melamine wastes. Difficulties encountered depend on the type and nature of the treatment. Generally, the difficulties center around flucuations in pH. Therefore, combination of urea and melamine wastes is technically feasible and pretreatment is generally not required.

C. By-product Utilization

There are no by-product uses of wastes nor are new by-products likely to be developed and marketed in 1968 to 1977.

D. Base Year New Waste Quantities

Waste Constituents	New Waste Quantities, lb/yr, reaching Watercourses in Base Year 1963*
BOD	NDA
SS	NDA
Urea and melamine	13.8×10^6
Formaldehyde	13.8×10^6

E. Projected Net Waste Quantities

		Summary of Base Year and Projected Net Waste Loads		
Year	Waste	Gross Waste Quantity Generated, lb	Percentage of Waste Reduced or Removed by Process Changes, Waste Treatment, and By-products	Net Waste Quantity Discharged, lb
1963	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	13.8×10^6	-0-	13.8×10^6
	Formaldehyde	13.8×10^6	-0-	13.8×10^6
1968	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	18.3×10^6	-0-	18.3×10^6
	Formaldehyde	18.3×10^6	-0-	18.3×10^6
1969	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	19.4×10^6	-0-	19.4×10^6
	Formaldehyde	19.4×10^6	-0-	19.4×10^6

* Figures based on discharge from condensation process without in-plant treatment and without additional treatment such as in a municipal treatment plant.

Year	Waste	Gross Waste Quantity Generated, lb	Summary of Base Year and Projected Net Waste Loads: Percentage of Waste Reduced or Removed by Process Changes, Waste Treatment, and By-products	Net Waste Quantity Discharged, lb
1970	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	20.0×10^6	-0-	20.0×10^6
	Formaldehyde	20.0×10^6	-0-	20.0×10^6
1971	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	20.8×10^6	-0-	20.8×10^6
	Formaldehyde	20.8×10^6	-0-	20.8×10^6
1972	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	21.6×10^6	-0-	21.6×10^6
	Formaldehyde	21.6×10^6	-0-	21.6×10^6
1977	BOD	NDA	NDA	NDA
	SS	NDA	NDA	NDA
	Resins	25.6×10^6	-0-	25.6×10^6
	Formaldehyde	25.6×10^6	-0-	25.6×10^6

IV. WASTE REDUCTION AND REMOVAL COST INFORMATION

A. Replorement Value and Annual Operation and Maintenance Expenditures of Existing Waste Removal Facilities (1966)

Removal Method	Replacement Value	Annual Operation and Maintenance Cost
Lagooning	$25,000/acre or $800/$10^6$ gal*	Small
Incineration	$150/gal/hr (typical flows--100 to 1000 gph)	$300/gal/hr
Municipal sewer	Not applicalbe	$220 to 850/$10^6$ gal**

* Assuming a lagoon depth of 10 ft.

**Sewerage districts use several methods for computing charges. Some base their charges on hydraulic flow alone; other determine their charges on the basis of BOD, suspended solids, chlorine demand, and flow. An example of such a rate schedule is given in Profile Study SIC-28218 "Phenolic Resins."

B. Capital Costs and Economic Life of Processing and Waste Removal Treatment Equipment

See Section IV-A for capital costs and annual operating and maintenance expenditures for waste removal treatment equipment. Economic life of treatment units is 10 to 30 years.

There are no reductions in processing costs due to modified technology or by-products recovery.

The incremental costs of applying the different techniques to an existing plant as differentiated from a new plant can be ascertained from Section IV-A.

SECTION 8

SIC 28218 PHENOLIC RESINS

The phenol-derived resins represent the oldest family of resins. A wide variety of products and uses make up the distribution pattern. The major uses are for inexpensive casting and plywood bonding. It is the virtue of cost that causes this product to compete with new more exotic resins. The process of manufacture has not changed since first inception and probably will not change. The phenolic products lose approximately 5% of the very troublesome phenol during synthesis. The cost removing phenol from process water is very high. The low rate of growth indicates that the product is in the plateau of its life cycle and is reflected in the following:

Year	Production, 10^6 lb/yr
1962	0.69
1963	0.76
1965	0.90
1967	1.05
1970	1.22
1977	1.50

I. PROCESSES AND WASTES

A. Fundamental Manufacturing Process

The fundamental manufacturing process for phenolic resins is a batch condensation polymerization of phenolics with formalin (a 40% solution of formaldehyde in water), the raw materials, phenolics and formalin, together with catalysts, miscellaneous additives and modifiers of a proprietary nature. These are charged into a jacketed reaction kettle and heated to initiate the reaction. Once initiated, the reaction is exothermic; heating is terminated, and cooling water is introduced into the jacket to control the reaction temperature. The mixture is refluxed until the contents separate into two layers, a heavy viscous resin layer and an aqueous layer. At this point, vacuum is applied and the temperature is raised to remove the water. The molten resin is drained into a pan where it solidifies on cooling.

A flow diagram of the manufacturing process is shown in Figure 15.

B. Significant Water Wastes

The significant water wastes from the production of phenolic resins are: (1) water introduction with the raw materials, (2) water formed as a product of the condensation reaction, (3) caustic solutions

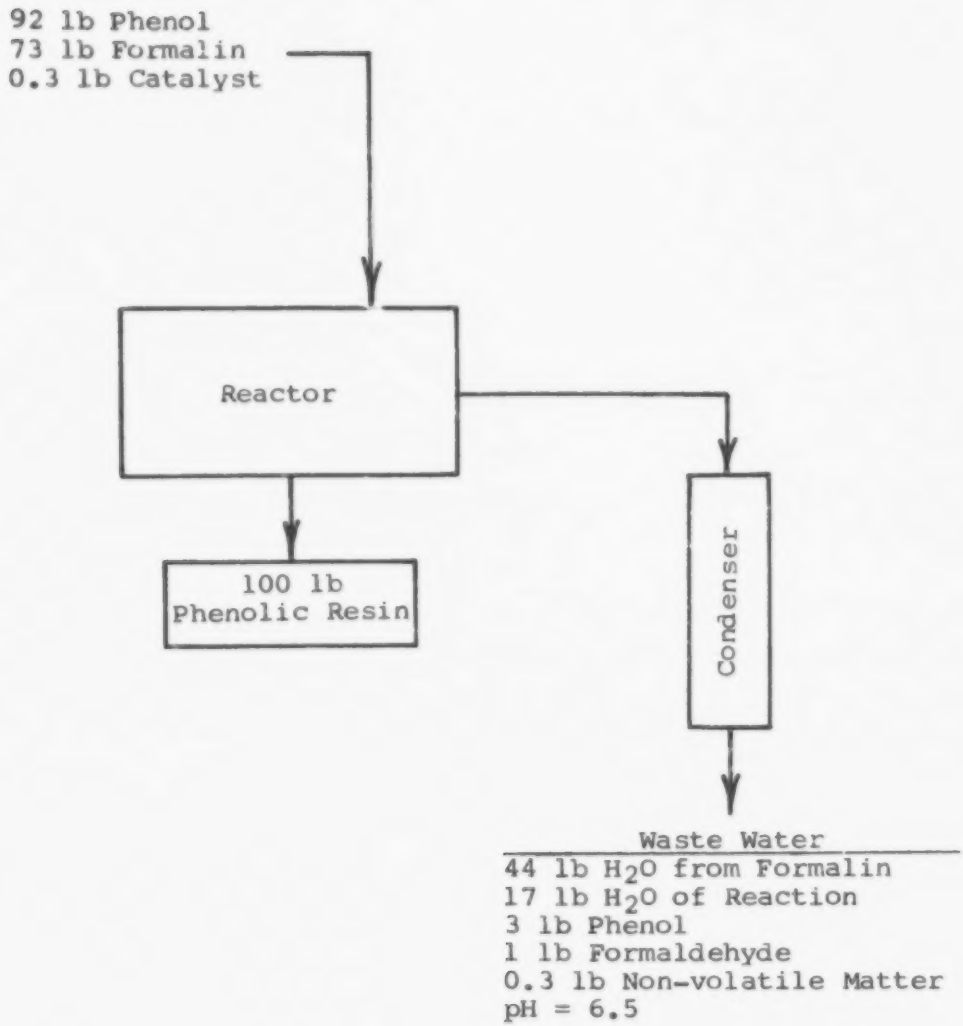

Figure 15

FLOW CHART FOR PRODUCTION OF PHENOLIC RESINS

used for cleaning the reaction kettles, and (4) blowdown from cooling towers. The first three waste waters constitute what is normally termed process water, and the fourth is a portion of the cooling water required to control the reaction temperature.

From Figure 15 the volumes of the various waste waters can be estimated. Per 100 lb of solid resin produced, 5.3 gal of water is introduced with the reactants and 2.0 gal of water is produced from the reaction. Caustic cleaning solution is required only when the formulation per kettle is altered significantly. A reasonable estimate of usage, prorated over a year's production, is 0.01 gal of a 2% sodium hydroxide solution per 100 lb of resin. Thus, the process water resulting from resin production is about 7.3 gal per 100 lb of resin. About 600 gal of cooling water is required to control the reaction; 42 gal is discharged to the sewers as cooling tower blowdown, and 558 gal is recirculated.

The waste waters discharged from resin plants have a temperature of about 85 to 90°F. Thus, thermal pollution is not a problem.

Thermal incineration of the process water can convert a water pollution problem to an air pollution problem whose magnitude will depend upon the fuel source, the volume of waste water incinerated, and the efficiency of the combustion.

C. Reuse of Process Water in 1964

Process water was not reused in 1964.

D. Industry Subprocess Mix

Condensation polymerization is the only process by which phenol-formaldehyde resins are produced. Production technology has shown little change over the past 20 years, and no new "advanced" technology is foreseen. Automated and continuous processing units have been introduced, but operator-controlled or semiautomated batch production is the most prevalent. The level of technology has little effect on waste water volumes or concentrations.

E. Difficult Waste Control Problems of Subprocess

There are no subprocesses.

F. Levels of Technology

Production technology has not changed significantly in the past 20 years, and no new or advanced process technology is foreseen. Thus, the batch condensation polymerization technology is representative of "typical," "older," and "newer" subprocesses. No data are available on the proportion of small, medium and large plants.

II. GROSS WASTE QUANTITIES BEFORE TREATMENT OR OTHER DISPOSAL

A. Waste Quantities and Volumes for an Average Size Plant Producing 50 million lb/yr

Waste Load, 10^6 lb/yr				Waste Water Volume,* 10^6 gal/yr
BOD	SS	Phenolics	Formaldehyde	
NDA	NDA	1.5	0.5	3.6

There is no significant variation in unit waste production for plants of significantly different production outputs. There is no significant variation in loading by season. Because of the batch nature of the production, hourly variations can be expected.

B. Total Waste Quantities and Waste Water Volumes

See Section III-A. Typical, older, and newer technologies are similar.

C. Total Waste and Waste Water Quantities per Unit of Physical Product

Waste Load, lb/lb product				Waste Water Volume, gal/lb
BOD	SS	Phenolics	Formaldehyde	
NDA	NDA	0.03	0.01	0.073*

D. Total Waste Quantities and Waste Water Volumes Produced in Base Year 1963

Waste Load, 10^6 lb/yr				Waste Water Volume, 10^6 gal/yr
BOD	SS	Phenolics	Formaldehyde	
NDA	NDA	22.8	7.6	55.5

These figures are based on production of 760 million lb of resin.

E. Projected Gross Wastes and Waste Water Volumes

Year	Production, 10^6 lb/yr	Waste Load, 10^6 lb/yr			
		BOD	SS	Phenolics	Formaldehyde
1968	1120	NDA	NDA	33.6	11.2
1969	1180	NDA	NDA	35.4	11.8
1970	1220	NDA	NDA	36.6	12.2
1971	1280	NDA	NDA	38.4	12.8
1972	1300	NDA	NDA	39.0	13.0
1977	1500	NDA	NDA	45.0	15.0

* Process water only

F. Seasonal Waste Production Patterns

There are no significant seasonal patterns in waste production.

III. WASTE REDUCTION PRACTICES

A. Processing Practices

1. Waste Reduction Efficiency (%) of a Given Subprocess Relative to Alternative Subprocesses

Theoretically, the use of solid paraformaldehyde in place of formalin can reduce the process water volume by 72%. In practice, if paraformaldehyde is used, some water would have to be added with the reactants. At present, formalin is almost always used for economic reasons. The absolute contamination loading, lb/lb of product, probably would not be altered by changing to solid paraformaldehyde, however.

2. Sequential Requirements and Interdependencies of Process Affecting Waste Production

Each time a formulation is significantly changed, the kettle must be cleaned with 2 to 5% caustic. Cleaning may be on a once-a-month schedule.

B. Treatment Practices

1. Treatment Removal Efficiency (%) of Waste Treatment Methods in Treating Waste from a Phenolic Resin Plant of Typical Technology

Removal Method	Normal Removal Efficiency, %			
	BOD	SS	Phenolics	Formaldehyde
Lagooning	NDA	NDA	NDA	NDA
	Lagoons are constructed so that there is no overflow of water. Evaporation andseepage balance inflow. Lagoon can produce malodors and result in air pollution complaints.			
Extraction of phenolics	NDA	NDA	96	0
	A typical analysis of the waste water discharged from a phenol extraction plant is as follows:			

Removal Method	Normal Removal Efficiency, % BOD	SS	Phenolics	Formaldehyde
	Phenol			1600 ppm*
	BOD			11500 ppm
	Chlorine demand			68 ppm
	Total solids			500 ppm
	Volatile solids			250 ppm
	Total susp. solids			40 ppm
	Volatile susp. solids			20 ppm
	pH			6.4
Thermal incineration	100	100	100	100
	Thermal incineration can cause air pollution, depending upon the fuel used and the efficiency of the oxidation process. Theoretically, the organic matter in the waste water is converted to carbon dioxide and water.			
Municipal sewage plant	NDA	NDA	NDA	NDA
	It is difficult to assign removal efficiencies for resin wastes because of admixtures with many other wastes including sanitary sewage.			

2. Rate of Adoption of Waste Treatment Practices

Reliable estimates are unavailable. However, phenol extraction processes were developed in the 1950s, and the blending of resin wastes with sanitary sewage and treatment in municipal sewage plants was accomplished about the same time. Thermal incineration is new but is being increasingly used, especially as a treatment method in new plants. Presently, less than 10 plants in the United States thermally incinerate a portion of their waste waters.

a. Recovery processes such as extraction methods must be employed before thermal incinferation or blending with other wastes before final treatment or disposal.

b. Extraction process can be single- or multistage and employ a variety of solvents. At present, extraction is the only recovery process used. Final treatment can be either thermal incineration, lagooning, or blending with sanitary sewage.

c. Extraction processes can be single- or multistage, and a variety of solvents can be used. Single-stage plants reduce the phenol content of the waste water from 5% to a level of 0.1 to 0.2%. Two-stage extraction reduces the phenol content to 0.01%. Single-stage units cost $70,000, and two-stage units about $90,000 (1958 dollars). The cost per day per pound of phenol removal is $12 for a single-stage plant and $88 for the second stage of a two-stage plant.

3. Percentage of Waste Discharged to Municipal Sewers

a. The exact percentage of waste discharged to municipal sewers is unknown, but in 1950 direct discharge to a watercourse was common without prior treatment. In 1967 many plants discharge to municipal sewers even after substantial in-plant treatment.

b. Municipal sewage authorities indicate a high degree of accommodation for phenolic waste. Studies have shown that both phenolics and formaldehyde are biodegradable in conventional biological sewage treatment processes, providing the concentration is maintained below toxic levels. The difficulties that do arise are due to fluctuation in pH. Therefore, combination of phenolics and municipal wastes is technically feasible, and pretreatment is generally not required.

C. By-product Utilization

There are no by-products, nor are new by-products likely to be developed and marketed in 1968-1977.

D. Base-year Net Waste Quantities

Waste Constituent	Net Waste Quantities lb/yr Reaching Watercourses in Base Year, 1963*
BOD	5.3×10^6
SS	0.02×10^6
Phenolics	0.91×10^6
Formaldehyde	7.6×10^6

E. Projected Net Waste Quantitites

Year	Waste	Gross Waste Quantity Generated, 10^6 lb	Percentage of Waste Reduced or Removed by Process Changes, Waste Treatment, and by-products	Net Waste Quantity Discharged, 10^6 lb**
1963	BOD	NDA	NDA	5.3
	SS	NDA	NDA	0.020
	Phenolics	22.8	96	0.91
	Formaldehyde	7.6	0	7.6

* Figures based on discharge from a single-stage extraction plant without subsequent treatment.

** Figures represent waste discharged from plant using single-stage extraction and do not reflect reductions affected by municipal treatment plant or any other additional treatment.

Year	Waste	Gross Waste Quantity Generated, 10^6 lb	Percentage of Waste Reduced or Removed by Process Changes, Waste Treatment, and by-products	Net Waste Quantity Discharged, 10^6 lb
1968	BOD	NDA	NDA	7.8
	SS	NDA	NDA	0.029
	Phenolics	33.6	96	1.35
	Formaldehyde	11.2	0	11.2
1969	BOD	NDA	NDA	8.3
	SS	NDA	NDA	0.03
	Phenolics	35.4	96	1.42
	Formaldehyde	11.8	0	11.8
1970	BOD	NDA	NDA	8.5
	SS	NDA	NDA	0.032
	Phenolics	36.6	96	1.47
	Formaldehyde	12.2	0	12.2
1971	BOD	NDA	NDA	9.0
	SS	NDA	NDA	0.034
	Phenolics	38.4	96	1.54
	Formaldehyde	12.8	0	12.8
1972	BOD	NDA	NDA	9.1
	SS	NDA	NDA	0.034
	Phenolics	39.0	96	1.56
	Formaldehyde	13.0	0	13.0
1977	BOD	NDA	NDA	10.5
	SS	NDA	NDA	0.039
	Phenolics	45.0	96	1.8
	Formaldehyde	15.0	0	15.0

IV. WASTE REDUCTION OR REMOVAL COST INFORMATION

A. Replacement Value and Annual Operating and Maintenance Expenditures of Existing Waste Removal Facilities (1966)

Removal Method	Replacement Value	Annual Operating and Maintenance Cost
Lagooning	\$25,000/acre or \$8000/10^6/gal*	Small

* Assuming a lagoon depth of 10 ft.

Removal Method	Replacement Value	Annual Operating and Maintenance Cost
Extraction		
first-stage	$12/lb phenol recovered/day	$6400/$10^6$ gal
second-stage	$88/lb phenol recovered/day	--
combined	$15/lb phenol recovered/day	$6400/$10^6$ gal
Thermal incineration	$150/gal/hr (typical flow -- 100 to 1000 gph)	$150/gal/hr
Municipal sewer	Not applicable	$220 to 850/$10^6$ gal*

Total treatment cost	462 x 10^3 $/yr
Capital goods depreciation	51 x 10^3 $/yr
Operating and maintenance	408 x 10^3 $/hr

B. Capital Cost and Economic Life of Processing and Water Removal Treatment Equipment

Total capital cost: $1,344 x 10^3

See Section IV-A for capital costs and annual operating and maintenance expenditures for waste removal treatment equipment. The economic life of extraction units if 10 to 30 years.

Schedule of Rates for Waste Treatment
by a Regional Sewerage Authority

1. Flow

Million Gallons per Quarter		Charge per Million Gallons
First 5	at	$413.86
Next 5	at	$272.23
Next 30	at	$200.29
Next 60	at	$ 95.72
Next 100	at	$ 50.02
Next 200	at	$ 41.39
Next 400	at	$ 36.52

* Sewerage districts use several methods for computing charges. Some base their charges on hydraulic flow alone; others determine their charges on the basis of BOD, suspended solids, chlorine demand, and flow. An example of such a rate schedule is attached.

2. Biochemical Oxygen Demand

Tons per Quarter		Charge per Ton
First 30	at	$ 21.07
Next 70	at	$ 19.75
Next 100	at	$ 17.80
Next 200	at	$ 15.72
Next 400	at	$ 12.61
Over 800	at	$ 10.48

3. Suspended Solids

Tons per Quarter		Charge per Ton
First 10	at	$ 29.22
Next 70	at	$ 28.24
Next 170	at	$ 23.86
Next 450	at	$ 13.51
Over 700	at	$ 12.84

4. Chlorine Demand*

Short Hundredweights per Quarter		Charge per Short Hundredweights
First 30	at	$ 12.59
Next 60	at	$ 11.50
Next 180	at	$ 11.07
Next 540	at	$ 10.51
Over 810	at	$ 9.86

The economic life of other methods is not known.

There are no reductions in processing costs due to modified technology or by-product recovery.

The incremental costs of applying the different techniques to an existing plant as differentiated from a new plant can be ascertained from Section IV-A.

SECTION 9

SIC 28219 MISCELLANEOUS RESINS

Miscellaneous resins are a chemically unrelated resins that have one common dimension, low-volume production. Several of the resins, as indicated, generate no water wastes. Some of the specialty resins are manufactured by just a few companies. Accurate treatment practices and costs were not available.

The accumulative production and projected growth rate for miscellaneous resins is, as indicated below, excellent

Year	Production, 10^9 lb/yr
1962	0.65
1963	0.76
1965	1.03
1967	1.25
1970	1.65
1977	2.00

I. POLYURETHANE

The principal use of polyurethane is in the production of plastic foams. Thermoplastic foams can be produced from styrene, vinyls, polyethylene, and cellulose acetate. Thermosetting foams can be produced from urethane, epoxy, phenolic, urea-formaldehyde, and silicones. In the case of urethane, either a chemically released gas (carbon dioxide) or a low-boiling solvent (fluorcarbon, F-11) is used for blowing. The densities range from 1.5 to 4 lb/cubic foot. The final product is poured and molded, poured-in-place, or sprayed-in-place.

Urethane foams have dominated the furniture applications for foamed plastics. Because of the ease of in-place application and high insulating value per unit volume (excellent K values), the potential growth for insulation is very good. For versatility, the urethanes can be mixed with vinyl, polyolefin, and styrene foams.

Urethanes are used mainly for foams (70% in 1962, est. 40% in 1970). Other uses are in elastomers, adhesives, fibers, paints, and coatings. The urethane plastic is synthesized in all cases by the reaction of a polyisocyanate (such as toluene diisocyanate) and a polyhydroxy compound (such as polyols, glycols, polyesters, and polyethers). The reaction mixture, including 0.1 to 0.5% catalyst (i.e., amines, metal soaps, etc) generates a gas that forms bubbles of controlled size and volume. The gas released is generally carbon dioxide. The manufacturing procedure provides for protection against contamination by water, which would change the rate and nature of the foaming reaction.

The production of polyurethanes creates no known water wastes. There is no known new technology in sight that would produce water wastes. It is expected that water wastes will not be significant through 1977.

The above-described excellent characteristics cause this product to have a high growth rate.

Year	Production 10^9 lb/yr
1962	0.200
1963	0.250
1965	0.380
1967	0.500
1970	0.985
1977	1.000

II. EPOXY

The earliest commercial epoxy resin and the one that still accounts for 80 to 90% of the epoxy resin epichlorohydrin. The term resin is somewhat of a misnomer when applied to the epoxies since these products are, for the most part, resin intermediates or prepolymers. They are initially thermoplastic materials that are converted in their final application into hard, tough, infusible thermosetting polymers by reaction with suitable hardeners (at least 100 different chemical are used to cross-link or harden this prepolymer.) No water wastes are created in the cross-linking, or hardening, step.

One important advantage of epoxies is that they can be formulated so that upon curing there is very little change in volume. This is of great advantage in tool and die work where the great toughness of epoxy resin can be used to replace expensive metal dies.

A very small number of manufacturers produce the linear prepolymer. This prepolymer is sold to approximately 100 formulators that supply specialty products to numerous small accounts in this business. There are hundreds of specialty applications for epoxies.

In a typical synthesis of the prepolymer, 2.5 gal of waste water is generated for each pound of epoxy resin produced. This would generate 425×10^6 gal of waste water per year. The nature and concentration of wastes were not available. The largest producer (50% of total production) stated that they have developed a process for synthesizing epoxy resins where no waste water is generated. Information obtained indicated that waste loads are "relatively small" and little waste treatment is required.

The following indicates that a moderate to good growth is expected for epoxy resins.

Year	Production, 10^9 lb/yr
1962	0.060
1963	0.090
1965	0.118
1967	0.150
1970	0.225
1977	0.260

III. ACETAL

The first commercial product was introduced in 1959. Since that time four other companies have brought out competing products. The product is relatively expensive; it competes mainly with metals.

The acetal resin, polyoxymethylene, is a highly crystalline polymer composed of repeating CH_2O groups. The process of manufacture remains undisclosed. The identification and quantification of water-borne wastes remain undisclosed. It is surmised that the product is formed by polymerization of formaldehyde follwed by a unique method of thermal stabilization. It is further surmised that since the final product is comprised of, at least 75% unbranched polyoxymethylene chains ($-OCH_2OCH_2-$) that production has proceeded with no release of either water units or other chemical fragments. On this basis, it is assumed that no significant water wastes are generated.

The following indicates relatively low production with a minimal growth pattern.

Year	Production, 10^9 lb/yr
1962	0.019
1963	0.030
1965	0.047
1967	0.050
1970	0.060
1977	0.070

IV. POLYCARBONATES

Polycarbonate resins are a new class of resins introduced commercially since 1960. There are now three suppliers. It is a specialty product with the following current usage:

	%
Appliance, lighting	34
Electrical, electronic	29
Safety, food, medical	13
Film and sheet	08
Plumbing	08
Miscellaneous	08

The general method of synthesis provides for preparation of a molding resin by reacting bisphenol A with carbonyl chloride. Hydrochloric acid is given off and must be neutralized. The resulting product is a thermoplastic resin consisting of bisphenol groups joined together by carbonate linkages. For modification various phenols and bridge molecules can be included in the structure of the product.

The water waste load is estimated at 1 gal/lb of product, and the quantity of the water per unit of production is not available.

The growth rate to a modest volume is reflected below.

Year	Production, 10^9 lb/yr
1962	0.005
1963	0.008
1965	0.030
1967	0.040
1970	0.090
1977	0.100

V. SILICONES

The first commercial production of silicones occurred in 1943. There are now four major producers of silicones. The resins are primarily used in electrical equipment because of their excellent dielectric properties and heat stability. Silicone elastomers are used for wire and cable insulation. The second largest consumer is industrial paints.

The manufacture of silicone fluids, silicone resins, and related products is quite simple in outline. After the production of suitable chlorosilane compounds, the desired product is produced by hydrolysis to form the polymer. For larger-scale production of silicone fluids, continuous processing is applied. For production of resins, batch processing is employed. An extreme range of products exhibiting a broad panorama of physical properties can be produced by starting with various chlorosilanes and varying the production procedure.

For each unit of silicone in the product, two moles of hydrogen chloride are produced. This generated hydrochloric acid is either neutralized or diluted before release to a stream. The final product must be carefully washed, which creates a certain organic waste load. The identification and quantification of this organic waste load was

not available for this study.[6] The waste water load is estimated at 4 gal/lb of product, or 60 10^6 gal/yr. One major supplier stated that they had a process in the pilot-plant stage that produced no waste.

The price of the silicones are relatively high. This product appears to have reached the plateau in its life cycle, as indicated below.

Year	Production, 10^9 lb/yr
1962	0.0085
1963	0.011
1965	0.012
1967	0.015
1970	0.015
1977	0.020

VI. NYLON 6

Nylon 6 is a linear polyamide with an average molecular weight of 19,000. The suffix 6 designates the monomeric starting material, which in this case is caprolactam. Nylon 6 accounts for about 25% of the total U.S. nylon production. The bulk of Nylon 6 production is used for carpeting, tire cord, and textiles. The remaining fiber production finds industrial usage in items such as seat belts, parachutes, rope, etc. Nylon 6 is also produced as extruded fiber and certain molded products.

The polymerization process for Nylon 6 is basically the same for all producers. Caprolactam is melted at 70 to 85°C under nitrogen in a large blending tank. Several additives are blended at this stage, including a molecular-weight regulator (0.05 to 0.15% acetic acid), a delustering agent (0.3 to 1.0% titanium dioxide), a catalyst (usually 2 to 5% water), and stabilizers for light and/or heat.

The charge is fed to a polymerication reactor and held for 20 hr at 250 to 270°C at 1 atm of pressure. The molten polymer is then extruded through a 1/8-in orifice into a water chill bath where it solidifies. The product is then chopped into short segments or chips. These chips contain about 9 to 11% water extractables. The water extractables contain 70% unreacted monomer, 10% higher lactam and 20% low-molecular-weight amino acids. The water solubles are not usually removed by the producer but are left in the pellets. The processers in turn, in many cases, do not remove the water solubles. What percent of the water solubles is removed from the total production and what percent of this is treated was not available for this study. One manufacturer has installed facilities to recover the unreacted monomer for reuse. What becomes of the low-molecular-weight amino acids in this process is unknown.

On the basis that most manufacturers leave the water solubles in the final product or recovers the valuable monomers, it is assumed that water wastes are minimal. The literature has several references to various methods of vacuum stripping for removing monomeric components. Considerable variance exists between sources on production figures and future volume projections. All agree that the growth rate is healthy, as reflected in the following.

Year	Production, 10^9 lb/yr
1962	0.033
1963	0.038
1965	0.050
1967	0.100
1970	0.150
1977	0.200

VII. COUMARONE-INDENE

Under the general classification of coumarone-indene resins are included both resins produced from coal tar by-products and those produced from petroleum refinery products (hydrocarbon resins). The major uses are for floor tile (25%) and rubber compounding (25%). The remaining 50% is used as an inexpensive extender for plastics and other miscellaneous uses.

The general manufacturing process for both raw material sources is very similar. The highly cracked hydrocarbon fractions from either coal-tar oils or from petroleum are processed. In the case of coal-tar oils, both coumarone and indene are present, leading to the generic name applied to the class. The recovery and use of a similar fraction, which is mainly highly unsaturated hydrocarbons, from petroleum is proportinately increasing. The production is currently 50/50 from each source. The general procedure for synthesizing the resin from cracked hydrocarbon fraction is to batch mix the hydrocarbon with a low-cost acid, i.e., 2 to 3% sulfuric acid. The oil-acid mixture is heated to effect polymerization. A neutralizing material is then added. The resultant product is either heated to drive off excess water and the residues are left in the product, or water washing may be applied. Accurate data relative to proportions of product production treated in each manner are not known. A typical figure of waste generation is 0.25 gal of waste water per pound of production. The biodegradeable waste generated is 0.001 lb BOD per lb of product.

Year	Production, 10^9 lb/yr
1962	0.290
1963	0.325
1965	0.325
1967	0.310
1970	0.300
1977	0.300

VIII. MISCELLANEOUS RESINS

The annual operating and maintenance expenditures of existing waste removal faculities for the miscellaneous resins* are:

Treatment cost	34×10^3 \$/yr
Capital good depreciation	13×10^3 \$/yr
Operating and maintenance	21×10^3 \$/yr

The capital cost and economic life of waste removal equipment for miscellaneous resins are:

Capital cost	$0.382\ 10^6$ \$/yr
Economic life	30 yr

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* Of those resins generating waste, only data on coumarone-indene resins were available.